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THE AUTHORS OF THE SEVERAL PAPERS ARE INDIVIDUALLY RESPONSIBLE FOR THE SOUNDNESS OF THE OPINIONS GIVEN AND FOR THE ACCURACY OF THE STATEMENTS MADE THEREIN.

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Art. I—The Tertiary Geology of Australia.

By F A SINGLETON, D.Sc.

[Read 9th November, 1939, issued separately 1st February, 1941.]

Contents.

Introduction.

At a symposium on Tertiary Formations of the Pacific Region at the First Pan-Pacific Scientific Conference (Honolulu, 1920), an account of the Post-Cretaceous Rocks of Australia was given by Richards (15). At the Second Congress (Australia, 1923), Chapman and Singleton (27) contributed a more detailed paper on the Tertiary Deposits of Australia, a supplementary note to which was furnished to the Fourth Congress (Java, 1929) by the author (43).

In the past decade not only have undoubted Eocene deposits been identified in Australia, but also considerable changes have taken place in the views of the joint authors above-mentioned, and their account no longer represents the views of either of them. Consequently the time seems ripe to offer an account of the present state of our knowledge of the Tertiary Geology of the Commonwealth of Australia, including Tasmania but not New Guinea.

The present paper seeks to cover a wider field than either of the preceding accounts, necessarily in outline only, so that for details the papers listed in the bibliography should be consulted.

Geographic Distribution.

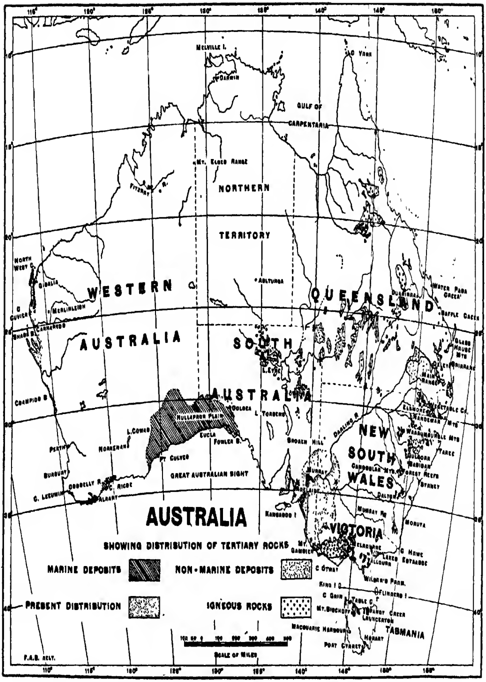
Of the three million square miles, in round figures, of the continent of Australia, marine Tertiary formations occupy about $6\frac{1}{4}$ per cent., of which outcrops are subordinate to areas in which they are covered by later deposits or by igneous rocks.

They form a discontinuous fringe from lat 21° 46′ S., long 114° 6′ E at North-West Cape in West Australia, along the western and southern coasts of the continent to lat 37° 50′ S, long 148° 5′ E near Lakes Entrance in Victoria, with small areas on the north-west coast of the island of Tasmania and on the islands of Bass Straits While their occurrence is chiefly along a coastline of about 5,000 miles, they are found inland for 250 miles in the basin of the Murray River, where they extend into New South Wales, and perhaps nearly as far in the little-known region north of the Great Australian Bight Over this vast area, extending nearly 1,350 miles north to south and 1,750 miles east to west, virtually nothing but reconnaissance work has been done except in the more populous areas of the south-east, in the States of South Australia, Victoria, and Tasmania, where the studies of a limited band of workers over the past three-quarters of a century have accumulated a considerable literature, both stratigraphical and palaeontological

Non-marine deposits are more widespread, notably in the interior of the continent, but can seldom be satisfactorily dated except in the south-east, where they come into relation with marine deposits or with igneous rocks whose age is otherwise determinable Elsewhere, particularly when unfossiliferous, it is seldom possible to subdivide them or even to distinguish them from post-Tertiary deposits

Igneous rocks are more particularly developed in Eastern Australia from Queensland to Tasmania, but again it is difficult to draw the boundary between Tertiary and Quaternary igneous activity, and it has not always been possible to do so on the map. More precise definition of age, by interrelation with marine deposits, is practically confined to Victoria, and in the other States physiographic evidence must be relied upon.

It will be seen that even the areal distribution of the Tertiary rocks is but imperfectly known, and it follows that the boundaries shown on the map must necessarily be accepted as tentative, as must, indeed, be regarded much of the account which follows



Map 1

Geological Map of Australia and Tasmania, showing distribution of Tertiary Rocks. Modified from geological map of the Commonwealth (3) and State geological maps

10793/40. [Page 3.]

Classifications of the Marine Deposits.

The Tertiary controversy in Australia has undergone such kaleidoscopic changes and is so far, even now, from finality that it is difficult for one unfamiliar with its detailed history to understand the literature. Consequently it seems desirable, before outlining the present views of the writer, to give a brief historical account to supplement those given by Pritchard (12), for the period prior to 1895, and by Richards (15) up to 1921

VIEWS OF McCOY AND THE VICTORIAN GEOLOGICAL SURVEY.

Although Professor (afterwards Sir Frederick) McCoy never expressed his views in the form of a correlation table, yet it is possible from publications to infer them and those of the Geological Survey of which he was the palaeontologist, and to translate them into the local nomenclature established since his lifetime.

In 1861 McCoy (280, p. 168) referred the beds between Mount Martha and Mount Eliza [Balcombe Bay = type Balcombian] to the Upper Eocene, but five years later (281, p. 323) adopted for them the newly introduced term Oligocene, while he regarded the greater part of the Victorian Tertiaries as Lower Miocene. Subsequently he always combated the prevailing contemporary view of an Eocene age, remarking in 1894 (168, p. 48) that the Muddy Creek and Schnapper Point [Balcombe Bay] beds were "of newer date than any true Eocene Tertiary type, such as the London clay"

From papers published between 1874 and 1882 (282-288) one can set out McCoy's views on correlation as follows —

Oligocene Near Mount Martha [Balcombe Bay = type Balcombian]; near Mount Eliza [Grice's Creek], Moolap, Ad 14 [Curlewis; later, as Outer Geelong Harbour, Ad. 12, to Miocene]; Fyansford. As Oligocene or Upper Eocene 2 miles NW of Cape Otway. As Lower Oligocene coast between Aire River and Castle Cove; Princetown, 3 miles W of Gellibrand River As Upper Oligocene. Shelford

Miocene Bird Rock Point, ½ mile W. of Spring Creek [Torquay = type Janjukian, as Lower, Middle, and Upper Miocene]; Waurn Ponds, Corio Boy, Boggy Creek, near Sale; Mitchell River, Bairnsdale. As Middle Miocene coast 1 mile W of Sherbrook River. As Upper Miocene Muddy Creek [upper beds]; Moorabool River, near Maude [upper beds].

Pliocene · By implication, Jemmy's Point, Gippsland Lakes [Kalimna = type Kalimnan]. As Lower Pliocene Mordialloc [Beaumaris, upper beds = type Cheltenhamian]; Flemington [Royal Park, lower beds].

It will be seen that McCoy would have regarded the Balcombian as antecedent to the Janjukian, but that he included with the former the Cape Otway and Aire Coastal sections, which others have referred to the Janjukian. He would also have regarded the

upper beds of Muddy Creek as pre-Kalimnan and the lower beds at Flemington as post-Barwonian, neither view being accepted by any subsequent author

McCoy's views were essentially those of the Geological Survey of Victoria, as summarized in 1887 by Murray (9), who recognized three principal groups—Lower Tertiary (Oligocene), Middle Tertiary (Miocene), and Upper Tertiary (Pliocene), and given more fully by Pritchard (12, pp. 358-9).

Views of Tate and Dennant.

In 1878, soon after his arrival in South Australia, Professor Tate (171) divided the marine beds at Aldinga into two series, later (47) called Eocene and Miocene, and those of the River Murray cliffs into three series, of which the upper was placed on the same horizon as Hallett's Cove and the upper Aldinga beds in South Australia and the Muddy Creek beds in Victoria. The lower Aldinga beds, though equivalent in part to the middle and lower Murray series, were considered on the whole inferior to them These views were set out in tabular form (47, p. liii) in the following year

In 1885 Tate (175), having restricted his upper Murravian series to the oyster beds, correlated instead the middle Murravian with the Muddy Creek beds, which in 1889 Dennant (83) showed to be divisible into two series. The lower, regarded as low in the Eocene, Dennant placed with the beds of Mornington [Balcombe Bay]; the upper, believed not older than Miocene, with those of Mordialloc [Beaumaris] As next younger than these latter, and probably early Pliocene, Dennant regarded the Ostrea limestone of the upper part of the cliffs at Portland Bay and the Glenelg River.

In the following year he discussed further (84) supposedly still younger beds on the Glenelg River, originally described by him in 1887 (82), under the name of Bankivia beds, as Pleistocene These constitute the type beds of the Werrikooian

Meanwhile Tate (177) had announced the discovery, by borings in the Adelaide plains [type Adelaidean], of marine Pliocene in South Australia, and had discussed (178) the Tertiary stratigraphy of the Adelaide area.

Still later Dennant (85) correlated with the upper beds at Muddy Creek, as Miocene, the strata at Jemmy's Point [type Kalimnan], and with the Eocene those of the Mitchell River near Bairnsdale. These two deposits were subsequently described in greater detail by Dennant and Clark (90, 91).

During the period 1893-6 Tate and Dennant, in a series of papers (183-185), discussed in detail the correlation of the marine Tertiaries of Australia, a summary of which had been given by Tate (49). These authors referred all the marine deposits classed as Oligocene and as Miocene by the Geological Survey of

Victoria, to the Eocene, in which they noted, however, two faunal types. One, the Aldinga-facies, which probably indicates a relatively low position in the Eocene, is represented in the deeper beds of the Adelaide bores and in Victoria at Cape Otway. The other, best known at Muddy Creek, is conspicuous in most Victorian sections, such as the Gellibrand River, Camperdown, Shelford, and the Geelong district, including Western Beach [Corio Bay], Lower Moorabool [Batesford-Fyansford] and Curlewis-Belmont, as well as the Murray River and Mount Gambier district in South Australia; probably also Schnapper Point [type Balcombian] and Bairnsdale. As to Spring Creek [type Janjukian] and Table Cape (Tasmania), the authors reserved their opinion, but considered at Birregurra there is a mingling of the two faunas.

The views of Tate and Dennant may be condensed as follows:—

Eocene. In South Australia: Wilson Bluff to Head of Great Australian Bight; Point Turton, Edithburg, Surveyor's Point, etc., on Yorke Peninsula; lower beds in Adelaide bores and at Aldinga; Kingscote on Kangaroo I.; River Murray Plain; Mount Gambier District.

In Victoria. Muddy Creek (lower beds); Portland, Glenelg River, and Apsley; Warrnambool, Camperdown; Port Campbell, Sherbrook River, and Gellibrand, Aire River and Cape Otway; Spring Creek [type Janjukian], Birregurra; Shelford; Maude (lower beds); Moorabool and Barwon Rivers, Geelong district, Schnapper Point [Balcombe Bay, type Balcombian]; Cheltenham [Beaumaris, type Cheltenhamian], Mitchell River, Bairnsdale.

In Tasmania: Table Cape.

Miocene. In South Australia: River Murray Cliffs (oyster-beds or Upper Murravian series), Adelaide; Aldinga Bay and Hallett's Cove.

In Victoria: Portland and Glenelg River (Ostrea-limestone); Muddy Creek (upper beds); Jemmy's Point [type Kalimnan].

Older Pliocene. Marine sands beneath mammaliferous drift of Adelaide Plain [type Adelaidean], South Australia.

Newer Pliocene. Glenelg River at Limestone Creek, Victoria [type Werrikooian]. These were later regarded as Lower Pleistocene by Tate.

Subsequently Tate, in one of his last papers (181), modified his views, notably as regards the Spring Creek beds, as follows:—

Post-Eocene (? Oligocene). Beaumaris (Cheltenham), Murray Desert, Table Cape, and Spring Creek [type Janjukian].

Upper Eocene: Muddy Creek, Gippsland Rivers, River Murray, around Port Phillip [includes type Balcombian], Gellibrand River, and upper part of Lower Aldingian Series.

Middle Eocene. Cape Otway and middle section of Lower Aldingian.

Lower Eocene. Chalk of the Great Australian Bight, lower part of Lower Aldingian Series, and Croydon Bore.

It is noteworthy that, like McCoy, Tate would have placed the Balcombian below the Janjukian, thus reversing Hall and Pritchard's sequence, yet he agreed with the latter authors in placing the Cape Otway and part of the lower Aldinga beds (included in the Janjukian by Hall and Pritchard) below those of Muddy Creek and Balcombe Bay.

Finally, in 1903, Dennant and Kitson (275), in a faunal catalogue, utilized the following:—

Eocene to Oligocene

Group A (including Lower and Middle Eocene of Tate) Aldinga, Adelaide Bore, etc, in S Australia Brown's Creek, Cape Otway, Aire Coast, etc, in Victoria

Group B (Upper Eocene of Tate) Murray River and Mt. Gambier in S Australia Glenelg River, Muddy Creek [lower beds], Gellibrand River, Camperdown, Birregurra, Shelford, Lower Moorabool [Fyansford, etc], Corio Bay, Mornington [Balcombe Bay, type Balcombian], Flinders and Mitchell River, in Victoria Tentatively included are the Victorian localities of Fishing [= Fisher's or Fischer's] Point on the Aire River, Waurn Ponds, and Maude.

Group C (Tate's post-Eocene, on which Dennant and Kitson express no opinion). Spring Creek [type Janjukian], Victoria. Table Cape, Tasmania

Group D (provisionally Oligocene) Murray Desert in S Australia Keilor, South Yarra, Royal Park, and Beaumaris [type Cheltenhamian] in Victoria, the presence of two series at the two last mentioned localities being regarded as unestablished

Miocene Hallett's Cove, upper beds at Edithburg, Adelaide, Aldinga and Murray Cliffs in South Australia Horsham; upper beds at Glenelg River, Muddy Creek, Shelford and Bairnsdale, Gippsland Lakes [Kalimna, type Kalimnan, etc]

Older Pliocene Dry Creek and Croydon Bores, near Adelaide, S Australia [Adelaidean]

Newer Pliocene Limestone Creek [type Werrikooian], Glenelg River, Moorabool Viaduct, Victoria.

Views of Hall and Pritchard

Tate's view as to the Eocene age of the Older Tertiary deposits was supported by Hall and Pritchard, who in 1895 (106) proposed their subdivision in Victoria, from above downwards, as follows:—

(1) *Clays of the Lower Muddy Creek Type.*—Muddy Creek, Gellibrand, Camperdown, Birregurra, Shelford, Murgheboluc, Southern Moorabool Valley (Fyansford, etc), Belmont, Lake Connewarre (Campbell's Point), Curlewis, Corio Bay, Altona Bay (bore), Newport (shaft), Mornington [Balcombe Bay], Bairnsdale (Mitchell River)

(2) *Polyzoal Limestone of the Waurn Ponds Type*—Waurn Ponds, Batesford, Maude [upper beds], Curlewis, Flinders, and perhaps at Airey's Inlet and Muddy Creek.

(3) *Clays and Limestones of the Spring Creek Type*—Spring Creek, Maude [lower beds] and perhaps North Belmont.

This is substantially the same as that set out, as their joint views, by Pritchard (12), except that the clays and limestones of Curlewis and Belmont are there included under No. 2, as a sub-heading, and that North Belmont is omitted under No 3, which is termed Lower Eocene and stated to be equivalent to the Lower Aldinga series in South Australia and probably to the Table Cape beds in Tasmania.

Within a year, in a rejoinder to Tate and Dennant's criticism (184), Hall and Pritchard withdrew (107) the Waurn Ponds

limestone as a separate type, and associated it, as well as North Belmont, with the Spring Creek beds, but referred the limestones of Batesford and the upper beds at Maude to the Southern Moorabool Valley beds, grouped with the lower beds of Muddy Creek. They maintained, however, their view that the Spring Creek beds were older than those of Muddy Creek, a sequence which they sought to support both stratigraphically and statistically

Still later these authors made an important innovation in the proposal (112) of a local nomenclature, in connection with which they offered the following correlation.—

Werrikooian (Pliocene) Limestone Creek [type], Victoria.

Kalimnan (Miocene) Jimmy's [Jemmy's] Point, Gippsland [type], upper beds at Beaumaris, Shelford and Muddy Creek, Victoria, and of the Murray River cliffs and at Aldinga, S Australia Also the marine sands of the Dry Creek and Croydon Bores, S Australia [Adelaidean]

Balcombian (Eocene) Balcombe's Bay [type] and Grice's Creek, Mornington, Bairnsdale; Altona Bay, Corio Bay; Curlewis, Belmont, Lake Connewarre, Southern Moorabool Valley [Batesford, Fyansford, etc], upper beds at Maude, lower beds at Shelford, Murghebolue, Camperdown, Fishing Point, Aire River

Jan Jucian [afterwards Janjukian] (Eocene) Spring Creek [type], Waurn Ponds, lower beds at Maude, Cape Otway, and Aire Coast, Victoria Lower beds at Aldinga, S Australia Table Cape, Tasmania

The omission of the Muddy Creek lower beds is probably accidental, since these were always referred to the Balcombian by these authors. The inferior position of the Spring Creek beds is contrary to the view of McCoy, Tate and Dennant, though the two latter associated the Cape Otway and lower Aldinga beds at the base of their sequence

Views of Chapman and his Associates

McCoy's views as to age and sequence were substantially those advocated for many years by Chapman, as palaeontologist to the National Museum, Melbourne, who in 1914 (22, 23, p. 50) set out his views, which may be thus summarized —

Oligocene (Balcombian) Mornington (Balcombe's Bay and Grice's Creek), Muddy Creek (lower beds, at Clifton Bank); lower part of the bores at Sorrento, Altona Bay and Newport; all in Victoria.

Miocene (Janjukian) Spring Creek, Torquay, Bairnsdale; Flinders, middle beds of Sorrento bore, lower beds at Flemington [Royal Park]; Keilor; Corio Bay, Fyansford, Moorabool Valley and Batesford; Curlewis, Waurn Ponds; Birregurra; Camperdown, Grange Burn limestone; Mallee bores; in Victoria Mount Gambier, Murray River, Murray desert, and lower beds at Aldinga, South Australia Table Cape, Tasmania

Of these he thought (22, p 299) that the Corio Bay, Bairnsdale and Fyansford beds probably represented the basal part of the

Miocene, to the middle of which he referred those of Torquay and Batesford, which latter, however, had already been shown by Hall and Pritchard to underlie the Fyansford deposits

Lower Pliocene (*Kalimnan*). Gippsland Lakes (Jimmy's Point), upper beds of Shelford, Muddy Creek, and bores at Sorrento and Mallee, lower Glenelg River, Victoria Adelaide and upper beds at Aldinga, S Australia

Upper Pliocene (*Werrikooian*). Limestone Creek, Glenelg River, upper beds of Moorabool Viaduct and Sorrento bore, Victoria, and Murray basin, S Australia

In 1923 similar views were set out in greater detail by Chapman and Singleton (27), who regarded the bulk of the Tertiaries of South-eastern Australia as Janjukian and chiefly Lower Miocene; the Balcombian as Oligocene, the Kalimnan, with which were included the upper marine beds of Adelaide (later the type locality of the Adelaidean), as Lower Pliocene, and the Werrikooian as Upper Pliocene

Thus in Chapman's view, maintained up to 1934, not only was the Balcombian antecedent to the Janjukian (270, p 20) but coeval with the latter, of Miocene age, were the thick lignites of Yallourn (subsequently type Yallournian) and the earlier volcanic rocks known in Victoria as the "Older Basalt"

Two years previously, however, Sir Edgeworth David, in the explanatory notes to his new geological map of Australia (2, table I. and footnote p 89), had on Chapman's authority placed the lowest beds of the Aldinga section, formerly correlated with the Janjukian, in the Oligocene and thus in the inferior position assigned to them by Tate more than half a century earlier.

Meanwhile the present author, largely as a result of studies, begun in collaboration with Chapman, of the Tertiary faunas of Fyansford and elsewhere in the Barwon River basin, had gradually become convinced that they were referable to the Balcombian, as had initially been claimed by Hall and Pritchard, and, by implication, McCoy, instead of to the Janjukian as had been maintained by Chapman since 1914. Since the author accepted the correlation of the lower Maude beds with the type Janjukian, and also the stratigraphic sequence between Maude and Fyansford first established by Hall and Pritchard, he was forced to accept also their view that Balcombian must succeed Janjukian, though he still agreed with Chapman and most of the workers of the past 25 years that both (comprised in the inclusive term Barwonian) were post-Eocene.

Consequently, in an outline of Victorian geology prepared late in 1934, the author (17) referred the Janjukian to the lowermost Miocene, the Balcombian to lower to middle Miocene, the Kalimnan to lower Pliocene, and the Werrikooian to the top of the Pliocene. The lignites of E. Victoria, under the term Yallournian, were classed as Oligocene, as was also the Older Basalt series.

Early in the following year Chapman, then Commonwealth Palaeontologist, and Crespin (26), gave a very full correlation of localities, but refrained from using the terms Balcombian and Janjukian, though they continued the use of Kalimnan and Werrikooian. Nevertheless the type localities of these two stages, Balcombe Bay and Torquay, above Spring Creek ledge, are both classed as Lower Miocene, while the beds below this ledge, which occurs in the lower part of the type Janjukian, are placed as Upper Oligocene, though qualified by the remark that the mollusca are typically lower Miocene and that " it may eventually be proved that the first 10 feet [from the base] of the Bird Rock Cliff section [i e. type Janjukian] is a passage bed between the Upper Oligocene and Lower Miocene " (26, p 121)

Thus it may be deduced that Chapman has largely reversed his views up to that date as to the sequence of these divisions of the Barwonian, since these authors now correlate the greater part of the type Janjukian with the type Balcombian, but consider the base of the former slightly antecedent to the Balcombe Bay beds, with which they now also group Fyansford and other disputed localities which Chapman had asserted to be post-Balcombian and to be referable to the Janjukian. They also regard Upper Oligocene and Lower Miocene as present in the lower Aldinga beds, S A It will be seen that Chapman and Crespin's view does not greatly differ from that of the present author, except as regards the supposed equivalence of the greater part of the Janjukian with the Balcombian, but that it does greatly differ from that previously expressed by Chapman and Singleton in 1923 and by the former (270, p 20) as recently as 1934.

Still more recently the present author (44) has suggested that the Adelaidean horizon, referred by Hall, Pritchard, Chapman and Singleton to the Kalimnan, might be interpolated, as Middle Pliocene, between it and the Werrikooian, an intermediate position first assigned to these beds, though as Lower Pliocene, by Tate

Summary of the Correlation of the Marine Deposits.

Eocene.

Paleocene to Middle Eocene horizons are as yet unknown in Australia, the earliest marine beds being those discovered in 1934 between Giralia and Bullara, near the head of Exmouth Gulf in North-west Australia. These are foraminiferal and bryozoan limestones, often with rolled quartz grains, forming a thin series (10 feet-30 feet?) overlying, apparently disconformably, the Upper Cretaceous Cardabia series which may be Campanian in its upper part (*sed vide infra*, p. 57).

The two occurrences at present known are at the northern end of the Giralia Range, a shallow anticlinal structure whose eastern

limb has been eroded through the Tertiary beds into the underlying Cretaceous (73, 74, 156). Both localities are near the Giralia-Bullara road one on the east flank of the Giralia anticline where the track to Bullara crosses the first low hills, the other in the bed of a creek at track crossing, nine miles from Bullara At both the characteristic foraminiferal genus is *Discocyclina*, accompanied at the former by *Pellatispira* and *Asterocyclina*, at the latter by *Pellatispira* and *Nummulites* These foraminiferal faunules have been referred by Chapman and Crespin (306) to the middle and upper parts of stage *b* of the East Indian sequence, which is approximately Upper Eocene They thus represent a stage, as yet unknown in South-eastern Australia, which may conveniently be referred to as Giralian.

Friable *Discocyclina* limestones have been reported still more recently (78) from Red Bluff and Cape Cuvier, more than 100 miles to the S S W.

The discovery near Merlinleigh Homestead, 115 miles east of Cape Cuvier, of an internal mould in ferruginous sandstone described by Miller and Crespin (569) as *Aturia* cf. *ziczac* (Sowerby), suggests that the Eocene may have once extended over a hundred miles inland from the present coastline

In South-west Australia soft calcareous shales from deep borings in King's Park and elsewhere near Perth, have recently been referred by Parr (338) to the Upper Eocene on the evidence of a very different foraminiferal faunule, which combines species identical with or similar to restricted Eocene forms in America, such as *Dentalina colei*, *Bolivinopsis eocenica*, and *Discorbis assulatus*, with a slight Oligocene element, including *Cyclammina incisa*, first described from the Lower Oligocene of New Zealand, and not uncommon in the Oligocene of Victoria

OLIGOCENE.

Limestones in the Cape Range, south of North West Cape, first recorded by Chapman (301) as Oligocene, largely on the identification of *Lepidocyclina* (*Eulepidina*) *dilatata*, were subsequently regarded as younger by Crespin (78), who reported also the eulepidines *L. papuanensis* and *L. chapmani* But according to Umbgrove (Leidsche Geologische Mededeelingen, Deel V., p. 69, 1931), *L. papuanensis* belongs to the horizon Tertiary *d* in the East Indies, being found in the Tempilan beds of East Borneo, and this horizon in the Cape Range is here referred to the Upper Oligocene

In Victoria, *Lepidocyclina* first appears on a later horizon, regarded by Chapman and Crespin (26) as Lower Miocene, but underlying it are beds which they have referred to the Upper Oligocene, including the micaceous foraminiferal marls with *Cyclammina* and *Victoriella* (as well as the underlying oil-bearing glauconite bed) of the lower part of the deep borings of the East

Gippsland area, and similar beds in bores at Portland and in N.W. Victoria. As already noted, they also included as Upper Oligocene the base of the Janjukian at its type section, together with the Aire coastal sections in Victoria and the lower part of the lower Aldinga beds in South Australia.

All these are regarded by the author as referable either to the Janjukian, as basal Miocene or possibly the summit of the Oligocene, or to an as yet unnamed pre-Janjukian stage, probably to be regarded as high in the Oligocene, and with them may be placed part of the marine beds of the Torquay bore, at the type Janjukian locality.

Underlying them in turn are the so-called lignitic beds, which are carbonaceous sands and clays apparently chiefly of estuarine origin, at the base of the East Gippsland, Torquay, Dartmoor, and Mallee bores in Victoria, and underlying the marine lower Aldinga beds and elsewhere in South Australia. These are referred to the Oligocene by the author, and to the Lower Oligocene by Chapman and Crespin. South-west of Torquay they outcrop, as dark carbonaceous sands with *Cyclammina*, in cliff sections (102) east of Anglesea, whence they may be termed Anglesean

Miocene.

Chiefly referable to the earlier Miocene, but perhaps in part extending back into the Oligocene, is the main development, both in thickness and in geographic distribution, of marine Tertiary strata in Australia

In the North West Division of Western Australia they are best developed in the North West Cape Range, on the eastern side of which are limestones 550 feet in thickness with abundant Lepidocyclinae (74). In addition to the eulepidine horizon above referred to the Upper Oligocene is one in which the eulepidines *Lepidocyclina murrayana* and *L. insulaenatalis* are associated with the nephrolepidines *L. angulosa*, *L. ferreroi*, and *L. verbeeki* and *Cycloclypeus* (78). This is Lower Miocene, to be correlated with the upper part of Tertiary *e* of the East Indies, and slightly older than the Batesfordian of Victoria. Overlying these are white foraminiferal limestones about 60 feet thick, apparently also Miocene, and still higher well-bedded white limestones 100 feet thick, of uncertain age (74).

Foraminiferal and bryozoan limestones also occur in the Rough, Giralia, and Waroora Ranges, and extend southwards to Salt Lake, north of Shark Bay, a total distance of nearly 160 miles.

From the Cape Range and Rough Range areas, and from borings at Carnarvon, Miss Crespin (78) has referred to the Middle Miocene foraminiferal limestones with, in addition to nephrolepidines, *Marginopora vertebralis*, *Flosculinella bontangensis*, and the widespread *Trillina howchini*, first described (343)

from the lower Muddy Creek beds (Balcombian) of Victoria These suggest a correlation with Tertiary *f* of the East Indies.

Still further south, at Champion Bay near Geraldton, marine Tertiary rocks of varied lithological types (7) form a coastal strip of which little is known.

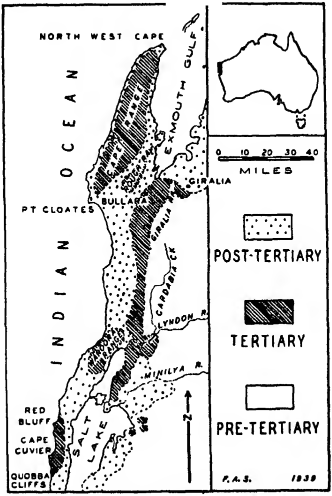


FIG 1.—Tertiary rocks of North West Australia. Modified from Raggatt, 1936 (156, pl. 3).

In South Western Australia the Plantagenet beds (7, 8, 133) are developed along the south coast near Albany, and from Cape Riche to the Phillips River. They consist chiefly of siltstones with a maximum thickness of 300 feet, resting upon granite, and

contain siliceous sponges and a small molluscan faunule (66, 271) with relations to the Janjukian of S.E. Australia. About 250 miles N.E. of Cape Riche, small exposures occur 120 miles inland near Norseman (8, 97), resting on pre-Cambrian rocks at 900 feet above sea level. They are mostly limestones with poorly preserved mollusca and bryozoa, except at Princess Royal, where silicisponge spicules (347) occur in a siliceous rock.

On the southern coastline Tertiary limestones are believed to extend from Israelite Bay, past Point Culver and Twilight Cove, to Wilson's Bluff near Eucla, where they pass into South Australia and reach as far as the Head of the Great Australian Bight, a total distance of about 500 miles. Little is known of this great limestone plateau, extending inland beneath the Nullarbor Plains and believed to cover an area approximating to that of Victoria Over most of this western part of the Great Australian Bight the high cliffs show apparently horizontal strata, chiefly the Eucla limestone (7).

At Wilson's Bluff (172) this comprises from below 188 feet of chalky white bryozoan limestone with two layers of flints and with echinoids, including *Salenia tertiaria*, becoming harder in its upper part, rich in brachiopoda, chiefly "*Magellania*" *insolita*; 12 feet of yellow bryozoan limestone with *Cellepora*; and 50 feet of grey to brown crystalline limestone with molluscan casts. Tate correlated the first two with the lower Aldinga beds of South Australia, and the third with the upper Aldinga beds, which are usually regarded as Kalimnan The author believes the crystalline limestones may, however, correspond with those of Ooldea (58), near the north-eastern limit in South Australia of the Nullarbor Plains, which are certainly pre-Kalimnan. In deep borings inland in Western Australia the Eucla limestone is reported to attain a thickness of 500 to 900 feet, when its lower portion might well range down into the Oligocene; it is, however, possible that these bores may have entered Cretaceous rocks.

In South Australia bryozoan limestones are found on Yorke Peninsula (52, 121, 176, 186) as well as on Kangaroo Island (116, 118, 174) and on the east side of Gulf St Vincent (69, 122, 185) from Gawler southward to near Sellick's Hill. Fossiliferous sands and clays occur in deep borings near Adelaide (180), and outcrop in the lower part of the cliffs at Aldinga Bay (122, 185). These, with the Cape Otway clays (110, 184) in Victoria, are regarded by the author (44) as either Janjukian or less probably referable to the stage which precedes it.

In the south-east of South Australia are the limestones and calcareous sandstones exposed along the River Murray cliffs (169, 175), of which the middle beds are doubtfully Balcombian, and cut by borings in the Murray Plains (68, 123, 182), while bryozoan limestones outcrop at Mount Gambier (190), whence they pass into Victoria.

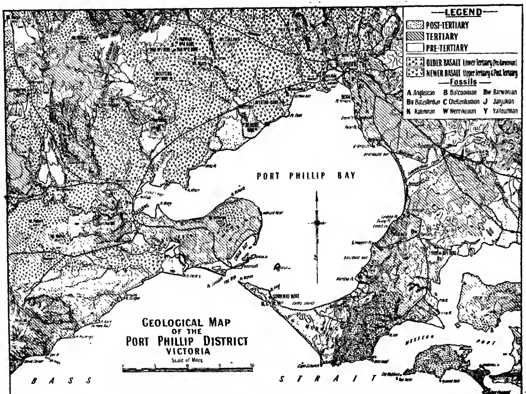
Portions of the ancient "Murray Gulf" extend into New South Wales, where Janjukian beds were cut at 647 feet in the Arumpo bore (94) and at 420 feet in the South Ita bore (44, 134), the latter 65 miles south of Broken Hill, and into Victoria, known by numerous borings in the Mallee and Wimmera districts. In Victoria, in addition to this north-western area, the principal regions of deposition are in the south west, more or less continuous beneath a basalt cover with that of South Central Victoria, and in East Gippsland in the south-east of the State.

Two main stages are recognizable in Victoria, which together constitute the *Barwonian System*, chiefly Miocene but perhaps extending back into the Upper Oligocene.

The earlier, in the author's view, is the *Janjukian stage* or group, typified by the lower beds (shelly clays and glauconitic marls) and upper beds (bryozoan limestones) of Bird Rock cliffs near Torquay (107, 183, 184). Near the base of the section, which is about 180 feet in thickness, are beds with *Spirulirostra curta*, closely related to the Miocene genotype *S. bellardi*, and a boring has proved a further 170 feet, giving a total thickness of about 350 feet. In Victoria the lower Maude beds (23, 106, 184), and in Tasmania the Table Cape beds (6, 131, 150, 166, 185), with *Prosqualodon davidis* (595-597), are here placed in the Janjukian, as Lower Miocene or even Oligo-Miocene, as are less certainly the Cape Otway and Aire Coast sections (50, 110, 184). Less than 1 per cent of the Janjukian molluscan fauna of about 250 species is still living.

The later or *Balcombian stage* is based on 35 feet of shelly marls, with an equal thickness proved by boring, at Balcombe Bay (111, 114, 135) near Mornington, Port Phillip, with similar beds at Grice's Creek (111, 135) nearer Frankston, and on the Mitchell River (91), Gippsland; in depth at Altona (23, 72, 108, 187) on Port Phillip and north-westerly towards Parwan (38); Murgheboluc (113), Fyansford (104), etc., in the Barwon River Basin; Gellibrand River (183); and lower beds at Muddy Creek (23, 83, 183) near Hamilton in Western Victoria. Here the marls contain over 400 species of mollusca, of which *Aturia australis*, closely related to the European *A. aturi*, and a new species of *Spirulirostra* are noteworthy, as is the pelagic miliolid *Trillina howchini*, known in the Miocene of Java (Tertiary *e*), Borneo (Tertiary *e* and *f*?), Phillipines, Pemba I. near Zanzibar, Irak, and I. of Paxos in Greece (273). They are rich in *Amphistegina lessonii* and the pteropod *Vaginella eligmostoma*, and are shown by a boring to be underlain by limestones with Lepidocyclinae, which outcrop nearby on Grange Burn.

The Batesford limestone (104, 299) with similar Lepidocyclinae, the commonest of which has been regarded as *Lepidocyclina tournoueri* (299), for which the term Batesfordian was



MAP 2.

Geological Map of the Port Phillip district, Victoria. Modified from map in A.N.Z.A.A.S. Handbook for Victoria, 1935.

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proposed (27), is similarly overlain by the Fyansford clay, here referred to the Balcombian.

The Batesfordian is thus either a late Lower or early Middle Miocene stage, also represented at Keilor (77), Flinders (27, footnote p. 989; 137), and in the East Gippsland bores (25), (characterized by nephrolepidines and a trybliolepidine but no eulepidines, and probably to be correlated with part of the East Indian Tertiary *f*), which immediately precedes the Balcombian (the view here adopted), or it may ultimately prove to be merely a calcareous facies of the latter. In either case a Middle Miocene age is probable for the Balcombian, of which a littoral facies may be represented by the limestones of the upper beds at Maude (106) and the ironstones of Keilor (77, 108) and the lower beds at Royal Park (70, 108, 158) near Melbourne

The Balcombian mollusca of the type locality total about 300 species, of which living species are not more than 1 per cent.

To some part of Barwonian time belong the bryozoan limestones of King (55, 80) and Flinders Islands (132) in Bass Straits and near Cape Grim (6, 10) and Marrawah (10) in North-West Tasmania.

The Upper Miocene may be represented in many cases by the stratigraphic break, marked by a "nodule bed" or rarely a slight angular unconformity, at the base of the Kalimnan (Lower Pliocene) where it rests on Barwonian deposits Perhaps Upper Miocene in part are white limestones on the western side of the North West Cape Range in Western Australia (74), and the beds immediately underlying the Kalimnan of the Sorrento (63) and East Gippsland (25) bores in Victoria

A probably Upper Miocene stage, which may be distinguished as Cheltenhamian, can be based on the marine ferruginous sands, overlying Balcombian clays just below low-water mark, of the cliffs at Beaumaris, near Cheltenham, Port Phillip (71, 108). These upper beds have usually been referred to the Kalimnan (Lower Pliocene), largely on the mollusca, but an Upper Miocene age is suggested by teeth of the cetacean *Parasqualodon* and by the presence of *Aturia*, a cephalopod elsewhere not surviving the Miocene

PLIOCENE

In North Western Australia this is doubtfully present in the limestones above-mentioned in the western side of the Cape Range, which have been provisionally termed Mio-Pliocene (74).

In South-Eastern Australia three stages have been proposed, and a fourth probably remains to be recognized.

The *Kalimnan stage* (Lower Pliocene) is based on the sandy clays of Kalimna (85, 90) in East Gippsland, which, with an extension in bores, are about 150 feet thick. To it are referred

sands and marls of the upper part of the borings of East Gippsland (25), Sorrento (63), the Mallee (57) and Wimmera districts, of outcrops at Muddy Creek (upper beds) (83, 272), in Victoria; and more doubtfully the upper beds of the Murray Cliffs (175) and of Aldinga (185) in South Australia They are neritic deposits of whose molluscan species, totalling about 110 at Kalimna and more than 150 at Muddy Creek, perhaps 10 per cent. are still living

The *Adelaidean stage,* known only in borings beneath the Adelaide Plains, South Australia, is based on the fossiliferous marine grey to white sands, about 160 feet thick, cut at about 300 feet below sea level in the bores at Dry Creek (177), the Abattoirs (126), and elsewhere (124, 125) They are shallow water deposits whose molluscan fauna, with perhaps 20-25 per cent of living species in a total of about 200, shows more relationship with the Kalimnan, with which it has often been correlated, than with the Werrikooian Nevertheless, it is probably post-Kalimnan, a conclusion supported by the foraminiferal faunule, and it may be tentatively regarded as Middle Pliocene (44)

The *Werrikooian stage* is typified by shallow water shell beds, on the Glenelg River near Limestone Creek, in Western Victoria (82, 84, 159), of whose molluscan fauna of about 200 species about 95 per cent are still living, and may be placed at the top of the Pliocene, with a gap representing an as yet undiscovered stage or stages between it and the Adelaidean This basal shell bed is not more than a foot in thickness, and is conformably overlain (159) by the Ostrea Limestone (84, 183), a series of 30 to 50 feet of flaggy sandy limestone, often false-bedded, widespread in south-west Victoria from Portland to the South Australian border, and notable for the first appearance of *Pecten (Notovola)*.

Doubtfully correlated with the Werrikooian are beds at Moorabool Viaduct (144) and in the Sorrento (63) and Mallee (57) bores, in Victoria; in a bore at Wingaroo (10, 26, 44, 526), Flinders Island, Bass Straits, and in the Tintinara bore in South Australia (57, 68, 123, 179); but demarcation from marine Pleistocene is often difficult.

Near Moruya on the south coast of New South Wales are ferruginous grits with poorly preserved shell moulds for which the author has with some doubt suggested an Upper Cainozoic age (21, p 337; 653, p. 41)

Definition and Discussion of Stage Names.

The following system and stage names have been proposed, or are herein suggested, for subdivisions of the Australian marine Tertiary strata:—Adelaidean, Aldingan, Anglesean, Balcombian, Barwonian, Batesfordian, Cheltenhamian, Gambierian, Giralian,

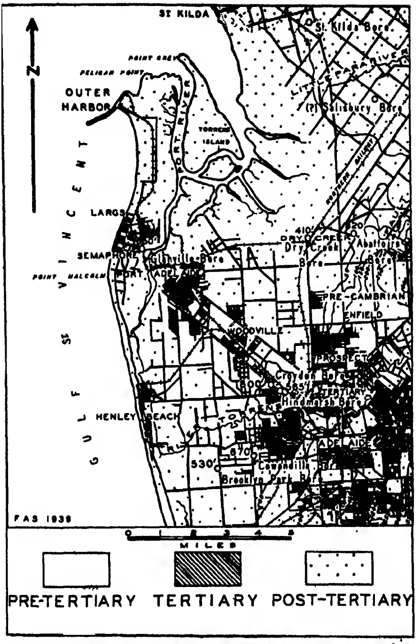

FIG. 2.—Geological map of Adelaide district, South Australia, with sites of bores cutting Adelaidean beds. Contours from Adelaide sheet, Military Survey of Australia, 1915.

Hamiltonian, Janjukian, Kalimnan, Murravian, Werrikooian, to which may be added Eyrian and Yallournian, proposed for non-marine deposits.

Adelaidean Stage.

Proposed by Howchin (4, p. 423) in 1928 for beds which in South Australia "are only known by borings, and as these are situated within short distances of Adelaide, it is proposed to distinguish them as the Adelaidean Upper Pliocene . . The presence of this marine bed has been proved by borings at Croydon, Dry Creek, the Abattoirs, Salisbury, and Smithfield, also on the coastal plains to the north of Adelaide, at St. Kilda, north of the Outer Harbour, and at Kidman's Bore, 3 miles to the northward of the last-named bore The bed is richly fossiliferous."

The best known of these borings, palaeontologically, are the Dry Creek bore, 5 miles north of Adelaide, and the Metropolitan Abattoirs bore, about 1½ mile to the east of Dry Creek For the Dry Creek bore, from the surface at 14 feet above sea level, Tate (177, p 172) gives the following sequence, the present writer's comments being added in brackets :—

0–120 feet Clays Pliocene or Mammaliferous Drift [Recent to Pleistocene]

120–320 feet Sands Not examined by Tate [? Pleistocene]

320–410 feet (bottom of bore) Fossiliferous sands Older Pliocene [Adelaidean]

For the Abattoirs bore, commencing at about 100 feet above sea level, the sequence described by Howchin and Parr (126, p 289) is as follows :—

0–341 feet. Alluvial sand and gravel Recent to Pleistocene

341-500 feet Fossiliferous marine sands. Upper Pliocene. [Adelaidean]

500–820 feet (bottom of bore) Fossiliferous clays and calcareous sandstones Miocene [Barwonian.]

While similar beds have been reported by Tate (180) in the Croydon bore, by Howchin (124, 125) in the Brooklyn Park, Glanville and Cowandilla bores, and by Mrs Ludbrook (140) in the Hindmarsh bore, all in the vicinity of Adelaide, the most suitable type sections, since unfortunately bore sections are all that are available, are those given by the two borings first mentioned

The Adelaidean may be defined as the interval of time represented by the deposition of the fossiliferous marine sands cut at 320 to 410 feet (306 to 396 feet below sea level). in the Dry Creek bore and at 341-500 feet (about 241-400 feet below sea level) in the Abattoirs bore, as well as those represented therein by non-deposition or erosion.

In the Dry Creek bore the foraminifera were determined by Howchin (in Tate 177 p 177) and the mollusca by Tate (177 pp 174 177) while for the Abattoirs bore the foraminifera have been exhaustively treated by Howchin and Parr (126) the

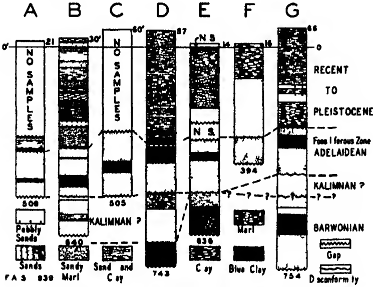

FIG 3 Comparative sections of Adelaidean beds near Adelaide A Brooklyn Park bore (124) B Cowandilla bore 125 C Hindmarsh bore (140) D Croydon bore (178) E Glanville bore (124) F Dry Creek bore (177) G Abattoirs bore (126

Bryozoa by Stach (431) and the pelecypods listed by N H Woods (549 pp 150 151) From these and other sources a list of the characteristic fossils in which the nomenclature but not the identifications of the mollusca has been revised appears to be —

Foraminifera *Flintina triquetra* Brady

Pelecypoda *Glycymeris convexa* (Tate) *Ostrea sinuata* Lamarck *Chlamys asperrimus antiaustralis* (Tate) *Codokia nuciformis* (Tate) *Miltha* (*Milthoidea*) *grandis* (N H Woods) *Lepton trigonale* Tate *Chioneryx cardioides* (Lamarck) *Electromactra howchiniana* (Tate)

Gasteropoda *Turritella* (*Ctenocolpus*) *trilix* Cotton and Woods *Tylospira marwicki* (Finlay) *Neodiastoma provisi* (Tate), *Polinices balteatella* (Tate) *Cymatiella sexcostata* (Tate)

Aldingan Stage

Though the introduction of this name has been attributed to Tate by Chapman (57 p 409) and by Chapman and Singleton (27 p 985) that author at the reference cited (47 p lm) uses only the terms Lower Aldinga Series and Upper Aldinga Series in a correlation table of South Australian Tertiary strata In one of his last papers Tate (181 p 107) in a Succession Table again referred to the Lower Aldingian Series which he subdivided under Lower Middle and Upper Eocene the Middle Eocene including the middle section of Lower Aldingian It is clear from the context however that Tate used the term Lower Aldingian not as a stage name but only as a convenient method of referring to the lower beds at Aldinga which he had originally described still earlier (171 p 121)

The first usage as a stage name in the amended form Aldingan is therefore that of Hall and Pritchard (112 p 79) who observed— In the cliff sections as described by Messrs Tate and Dennant Miocene overlies Eocene and the term Aldingian as used by them includes both sets of strata If it be confined to the lower series only it might perhaps be employed though it violates the principle that a name should not be given where two distinct series are in contact As we differ from the views of Messrs Tate and Dennant on the question as to its equivalence or otherwise with the Spring Creek series a type name may be thought desirable though our own views are opposed to its use

This correlation by Hall and Pritchard of the lower beds of Aldinga with the beds of Spring Creek (type locality of the Janjukian stage) was accepted by Chapman (23 pp 50 51 57 p 409) and by Chapman and Singleton (27 p 986) though Tate (181 p 107) had placed the Spring Creek beds on a later post Eocene horizon Apparently Chapman and Crespin (26 p 125) would place part of the lower beds at Aldinga on a slightly earlier horizon than those of Torquay (i e Spring Creek) and the writer has also considered this possibility (44)

If the term Aldingan be used for a stage it seems necessary that it should be confined in meaning to the Lower Aldinga Beds which was in fact the restricted sense employed by Tate and Dennant (185 p 141) when referring to the Aldingian fauna

As it has been used in two senses as Hall and Pritchard the introducers of the term were opposed to its use and as doubt exists as to its equivalence or otherwise with the Janjukian it seems wiser to reject at the present time the Aldingan as a stage name

Anglesean Stage

Here proposed for the black sandstone and sandy clays of the coastal cliffs extending from near the mouth of the Anglesea River east north easterly for about 2 miles towards Point Addis

in the Parish of Jan Juc, Victoria At Demon's Bluff, near the centre of the section, the cliffs are over 250 feet in height, but are much scarred by landslips, and the relations of the beds are more clearly seen towards the Anglesea end

On the axis of a gentle anticline, about a third of a mile north-east of the mouth of Anglesea River and half a mile east of the Anglesea bridge, a nearly vertical cliff section shows 41 feet of black sandstone overlain by 47 feet of white sands The junction between them, at a spot 150 yards to the south-west, dips at 4½ degrees to the north-west. The dark-coloured somewhat carbonaceous sandstone commonly shows lighter coloured branching markings which are presumably algal, while locally the foraminiferal genus *Cyclammina* is abundant and, with the tooth of *Odontaspis contortidens* Agassiz recorded by Hall (102, p 47), attests the marine origin of these poorly fossiliferous beds. The absence of a rich shelly fauna renders the locality by no means ideal as a type section, but nearly all other occurrences of beds correlable with the Anglesean, as in the East Gippsland, Mallee, and Dartmoor areas, are known only from borings and are thus unsuitable for selection.

The upward limit of the Anglesean is given by the overlying unfossiliferous white sands, but its downward extent, in the absence of borings, remains uncertain

The Anglesean may be defined as the interval of time represented by the deposition of the dark-coloured sands with Cyclammina *of the cliff sections between Anglesea and Point Addis, as well as those represented therein by non-deposition or erosion.*

BALCOMBIAN STAGE

This was introduced in 1902 by Hall and Pritchard (112, p. 78) as follows · " *Balcombian.* The clays and limestones of Balcombe's Bay contain another distinct fauna The beds are sometimes spoken of as at Mornington, but the locality we give is more exact "

At the type locality, which is a coastal section on the eastern shores of Port Phillip, Victoria, immediately to the north of the old cement works near the northern end of Balcombe Bay, and about a mile and a half south of Mornington, the fossiliferous clays or marls, with interbedded concretionary hard limestone bands, have been described by Hall and Pritchard (111, p. 39).

The richly fossiliferous marls are exposed chiefly between tide marks, but fossils become scarcer and more fragile in the cliff section, in which the marls have a thickness of about 35 feet. They are overlain by ferruginous sands and grits, with which the junction is sharp but even. Boring has shown the calcareous

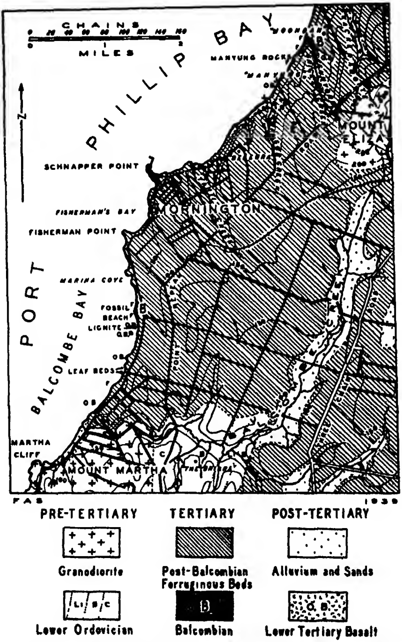

FIG. 4—Geological map of Mornington district, Victoria. Modified from Kitson, 1900 (135), and unpublished mapping by R. A. Keble. Contours from Cranbourne sheet, Military Survey of Australia, 1912. J, Jurassic, F Balcombian fossils.

marl to persist for 35 feet, and to be succeeded in depth by sandy clays, sands, and ligneous clays, and this apparently non-marine series is in turn underlain by basalt

It is clear that from the original description the ferruginous series, though subsequently referred to the Balcombian by Pritchard (155, p. 937), must be excluded from the definition of the stage, though it is reasonable to include the extension in depth of the calcareous marl proved by the boring, Bore No 6, Parish of Moorooduc (36, p 30)

The cliff section (k-p) beach floor (h-j), and bore (a-g) give a sequence as follows, totalling 197 feet

(*p*) 5 feet mottled clay
(*o*) 5 feet ironstone
(*n*) 4 feet ferruginous sandstone
(*m*) 2 feet ferruginous grit
(*l*) 10 feet ferruginous fine sandstone
(*k*) 35 feet grey clays with selenite crystals in upper part
(*j*) 1 foot septarian limestone nodules
(*i*) 3 inches grey shelly clays.
(*h*) 1 foot grey clays with discoloured markings of seaweeds (?).
(*g*) 35 feet calcareous marl
(*f*) 17 feet sandy clay
(*e*) 24 feet sand.
(*d*) 2 feet ligneous clay
(*c*) 4 feet coarse sand.
(*b*) 33 feet ligneous clay.
(*a*) 19 feet hard basalt

Depth bored 134 feet

Beds (b)-(f) constitute 80 feet of apparently non-marine strata, perhaps to be referred to the Yallourn series; beds (g)-(k) a fossiliferous marine series totalling 72 feet, in which most Balcombian fossils come from the richest bed (i), though fossils also occur above and below; and beds (l)-(p) belong to a ferruginous series, here 26 feet thick, which is widespread on the Mornington Peninsula.

The Balcombian may be defined as the interval of time represented by the deposition of the grey marls and concretionary limestone bands constituting beds (g)-(k) in the above sequence at Balcombe Bay, as well as those represented therein by non-deposition or erosion.

At the type locality the foraminifera have been dealt with by Chapman and his colleagues (298, 307, 310) in a monograph of the Balcombian Foraminifera of Port Phillip; the bryozoa were listed by Maplestone (423); the mollusca by Hall and Pritchard (111), and the latter and other groups by Dennant and Kitson (275); in the last three cases under the name Mornington, which refers to this section, as do "Schnapper Point," "Mount Martha," "between Mount Eliza and Mount Martha," and even "Hobson's Bay," of the earlier authors.

Characteristic mollusca include.—

Pelecypoda. *Limopsis morningtonensis* Pritchard.

Gasteropoda: "*Cerithium*" *apheles* T. Woods, *Umbilia eximia maccoyi* Schilder, *Austrotriton textilis* (Tate), *Chicoreus lophoessus* (Tate), *Dennantia ino* (T. Woods), *Volutospina antiscalaris* (McCoy), *Bathytoma rhomboidalis* (T. Woods), *Conus ligatus* Tate.

Pteropoda: *Vaginella eligmostoma* Tate

Cephalopoda: *Nautilus balcombensis* Chapman.

Less common but apparently restricted species include:—

Pelecypoda "*Chlamys*" *dichotomalis* (Tate), *Eucrassatella dennanti* (Tate)

Gasteropoda: *Turritella* (*Colpospira*) *platyspira* T. Woods, *Gigantocypraea gigas* (McCoy), *Solutofusus carinatus* Pritchard, *Pterospira hannafordi* (McCoy).

Barwonian System

In 1904 Hall and Pritchard (113, pp 297-8) proposed this name, as a Barwonian Series, in these words: "In the paper in which we proposed the names Balcombian and Janjukian, we indicated the existence of certain beds which undoubtedly belonged to the older series comprised under these two names, which are clearly distinct from the younger Kalimnan, but which from the smallness of the collections available, we did not care to refer definitely to either Balcombian or Janjukian. In other words, the palaeontological differences between Balcombian and Janjukian series, though of importance, are not nearly so marked as between them and the Kalimnan. On these grounds we think it advisable that a name should be given which will comprise both Balcombian and Janjukian. The former series is extensively developed in the Barwon basin, and the latter at its typical exposure at Spring Creek, south of Geelong, is not far from the borders of the same basin, so that the name Barwonian is suggested."

The name is thus given to cover both Balcombian and Janjukian, and is *not* defined in terms of any type locality within the Barwon basin, in which the beds are, indeed, referred by these authors to the Balcombian. Chapman (57, p. 409) was therefore mistaken in believing the Barwonian to be "typified in the series from Red Hill, Shelford, through Inverleigh, Murgheboluc, down the Barwon valley to Fyansford," an error which had previously led him (56, p. 371) to discard the term Barwonian on the grounds that its members were included in the term Janjukian, to which he had referred (see Chapman and Singleton, 27, p 986) the Tertiaries of the Barwon basin, instead of to the Balcombian as had done Hall and Pritchard.

The Barwonian may be defined as the interval of time represented by the Janjukian and Balcombian as herein defined, as well as such as may intervene between them

Batesfordian Stage

The first use of the term Batesfordian was in 1914 by Chapman, who stated (23, p. 49), in reference to the white polyzoal limestone in bore No. 11 of the Victorian Mallee district—"The fauna altogether showed a strong Aldingan and Batesfordian aspect; both Aldinga (lower beds) and the Batesford Limestone being of Janjukian age" Apparently Chapman had no intention of using the term as a stage name, for it is not included in the list of subdivisions of the Cainozoic beds given by him in his account of the Cainozoic Geology of the Mallee Bores (57, pp 409-411).

Accordingly, the first formal proposition of the Batesfordian stage was by Chapman and Singleton (27, p 986) in 1925, as follows:—"*Batesfordian*—Typified by the foraminiferal and polyzoal limestones of the quarries on the Moorabool River near Batesford, in the Geelong district, Victoria. These have been referred to by one of us (F.C.) to the Janjukian, and by Hall and Pritchard to the Balcombian" Later in the same paper (27, p. 990), it is stated that "Another calcareous facies of the Janjukian, characterized by the abundance of *Lepidocyclinae*, is the Batesfordian, to which are referred the foraminiferal and polyzoal limestones of Batesford, near Geelong, the junction of Grange Burn and Muddy Creek, near Hamilton, Violet Creek (in the same district), Green Gully, near Keilor, and Cape Schanck and Flinders, to the south of Port Phillip These Batesfordian localities have all been relegated to the Balcombian by Hall and Pritchard."

The writer has already indicated his belief (*supra*, p 19) that the Batesfordian is a stage immediately antecedent to the Balcombian.

At the time of proposition of the name there were two limestone quarries on the Moorabool River, a little more than a mile south-east of Batesford. One, on the left bank of the river, is known as the Upper Quarry, from which was formerly obtained a building stone termed "Moorabool Stone," a brownish dense limestone consisting largely of Lepidocyclinae. Hall and Pritchard (104, p. 11) gave the hill section at this locality, from above downwards, as follows:—

"Basalt	75 feet
Incoherent sandy material, with calcareous concretions	50 feet
Yellow clay, with calcareous concretions	5 feet.
Polyzoal limestone	20 feet.
Orbitoides [*recte* Lepidocyclina] limestone	20 feet.
Total	175 feet"

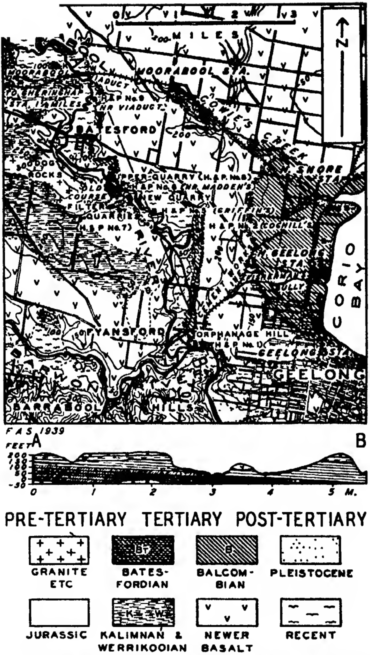

FIG 5.—Geological map and section of Batesford district, near Geelong, Victoria. Modified from Quarter-sheets Nos. 24 N.E. and S.E., Geological Survey of Victoria, 1863, with emendations and additions. Contours from Geelong sheet, Military Survey of Victoria, 1914. Fossiliferous localities: B, Balcombian; Bt, Batesfordian; Bw, Barwonian; K, Kalimnan; W, Werrikooian.

[Page 36.

The other, on the right bank of the river about half a mile south of the building stone quarry, was known as the Dryden or Filter Quarries, formerly worked for lime-burning and cement-making, as well as for the manufacture of dripstone filters from the compact limestones at the base of the section Chapman (299, p. 264) recorded the sequence, from below, as being 22 feet of pure white or cream-coloured friable limestone, composed largely of Lepidocyclinae, and gradually passing upwards into polyzoal rock with fewer Lepidocyclinae Over this were 14 feet of fine-textured pale bluish clay.

Neither of these quarry sections is at present visible. The building stone quarry has been partly absorbed and partly covered by dump material from a greatly enlarged Upper Quarry adjoining to the south, formerly worked by Australian Cement Ltd. The Filter Quarries have been buried by dumps from this and from the company's new quarry on the right bank of the river, about a quarter of a mile further downstream. Upon development of the new quarry, the old upper quarry was abandoned in 1931, and the Moorabool River was diverted through it, since when much of the fine section on the east side has been obscured by slumping Approximate thicknesses, from above, of this section are —

- (*g*) 6 feet Basalt
- (*f*) 16 feet White sands
- (*e*) 15 feet Brown ferruginous sands.
- (*d*) 30 feet Yellow and grey clays and marls, more calcareous towards the base
- (*c*) 30 feet Earthy limestones.
- (*b*) 30 feet White bryozoan limestone, weathering yellowish brown, and passing downwards into
- (*a*) 45 feet Lepidocycline limestone.

172 feet

The floor of the quarry, now flooded, was below river level, and a shaft sunk below it disclosed a further 50 feet of lepidcycline and bryozoan limestone, towards the base becoming rich in granitic quartz grains derived from the adjacent Dog Rocks granite, which doubtless forms the bedrock In the new quarry the limestones, which are at least 120 feet thick, are similarly overlain by about 30 feet of clays, here less oxidized and therefore grey in colour, which, like that of the filter quarries, contain a shelly fauna (107, p. 161) similar to that of the Fyansford clay (104, p. 19), with which they are continuous, and which the writer, like Hall and Pritchard, refers to the Balcombian.

The Batesfordian may be defined as the interval of time represented by the deposition of the* Lepidocyclina*-bearing limestones of the Batesford quarries, as well as those represented therein by non-deposition or erosion.

The limestone fauna of the Filter and Upper Quarries has been listed by Hall and Pritchard (104, p 18; 107, p. 159), and by Chapman (299) in a study of the foraminifera, which were later also studied by Heron-Allen and Earland (324).

The characteristic foraminifera are:—

Lepidocyclina (*Nephrolepidina*) cf. *tournoueri* Lemoine and Douvillé, *L* (*N.*) *martini* Schlumberger, *L* (*N.*) *marginata* (Michelotti), *Cycloclypeus communis* Martin, *Operculina victoriensis* Chapman and Parr, *Amphistegina lessonii* d'Orbigny, *Rotalia verriculata* Howchin and Parr, *Gypsina howchini* Chapman The commonest associated larger fossils are *Phyllacanthus duncani* Chapman and Cudmore and "*Chlamys*" *murrayanus* (Tate).

Cheltenhamian Stage

Here proposed for the fossiliferous ferruginous sandstones of the lower part of the coastal cliffs and the underlying "nodule bed" at Beaumaris, near Cheltenham, Port Phillip (31, 108)

The "nodule bed" appears above low tide mark on the axis of a gentle anticline immediately north-east of the boatshed and opposite the Hotel It consists of a 3-inch layer of grit with well rounded clear quartz grains and larger subangular fragments of yellowish reef quartz, together with numerous ferruginous and slightly phosphatic concretions of cylindrical form, up to 5 or 6 inches in length This nodule bed contains a rich fauna of sharks' teeth, of which *Isurus hastalis* (Agassiz) and *Heterodontus cainozoicus* (Chapman and Pritchard) are among the commonest, together with remains of other fishes and cetacean bones The worn condition of many of the teeth suggests a remanié origin for some of the fossils, among which invertebrates are rare, though *Placotrochus deltoideus* Duncan, *Magadina* aff *compta* (Sowerby), and *Zenatiopsis angustata* Tate occasionally occur

The nodule bed, which marks a stratigraphic break, rests upon an eroded surface of impure limestone or calcareous sandstone, apparently the calcified and hardened upper portion of the Balcombian strata, chiefly marls, which form the sea floor below low tide mark opposite the boatsheds. From limestone pebbles of the beach shingle, derived from this older series, a small faunule (108) has been obtained which includes typical Balcombian mollusca such as "*Cerithium*" *apheles* T. Woods and *Pterospira hannafordi* (McCoy). At its highest point the nodule bed is about 1 foot above beach level, and is overlain by a 2-inch band of *Placunanomia* cf. *ione* (Gray), followed by ferruginous sandstones which are soon obscured by hill wash Apparent dips of 1° S.S.W. and 1½° N.N E. soon carry the nodule bed beneath the beach floor, which it occupies, however, between tide marks immediately south-west of the boatshed.

The cliff section (A) opposite the Beaumaris Hotel, at a spot 70 feet south-west of the boatshed and the centre line of Bodley-street, is as follows —

(ix) 4 feet (?) white sands.
(viii) 6 feet ferruginous sandstone
(vii) 8 feet ironstones
(vi) 14 feet ferruginous sandy marl (?)
(v) 9 feet sandy marl with *Lovenia*
(iv) 6 inches with decomposed shells (*Eucrassatella*, etc).
(iii) 8 feet marly sands with calcareous concretions.
(ii) 1 foot fine sandy marl, with top 4 inches locally laminated.
(i) 6 inches calcareous sandstone, downward continuation hidden by beach sand

51 feet

Bed (i) appears lithologically similar to that *below* the nodule bed north-east of the boatshed, but the resemblance is probably due to secondary calcification, since here the nodule bed, exposed on the beach floor at low tide, must be about 1 foot below the base of the visible cliff section

Bed (iii) is notable for undulations which, though perhaps in part concretionary, appear to be actual folds, possibly due to "slumping" after deposition These "folds" are truncated by bed (iv), with very decomposed bivalves, of which the commonest is *Eucrassatella* cf *camura* (Pritchard), and occasional quartz pebbles up to ½ inch, also suggesting a break at the base of this bed The succeeding bed (v) contains abundant *Lovenia forbesi* (T. Woods) and occasional *Monostychia* cf *australis* Laube. Beds (vi) to (viii) are apparently unfossiliferous, but are largely masked at this spot, so that it is uncertain if (viii) continues to the top of the cliff or if (ix) is present To the south-west, however, where the cliff top rises, bed (ix) constitutes a capping to the ferruginous beds of about 10 feet of white sands, perhaps Pleistocene, if they are the source of the extinct kangaroo remains which have been recorded from the beach shingle (605).

On the north-east of the boatshed the cliffs for about 300 yards are completely broken down and masked by vegetation, but good cliff sections occur from Ray-street eastwards. At a spot (B) 150 yards east north east of the steps leading to the former baths, a nearly vertical cliff section shows:—

(*d*) 8 feet white sands.
(*c*) 19 feet ferruginous sandstone with hard bands.
(*b*) 17 feet pale fine sandstone or sandy marl
(*a*) 3 feet brown sandstone with shells near high water mark

47 feet.

The nodule bed is not exposed, but may be reached by digging for about 2 feet in the beach shingle (108). Bed (*a*) at the base of the cliffs contains a typical shelly fauna, in which

Limopsis beaumariensis Chapman is perhaps the most abundant species Bed (*b*) contains in its lower part *Neotrigonia acuticostata* (McCoy) and occasional large *Cucullaea praelonga* (Singleton), particularly just past a point (c) about 50 yards further easterly, where bed (*a*) contains hard shelly bands with *Eucrassatella* and *Aturia*

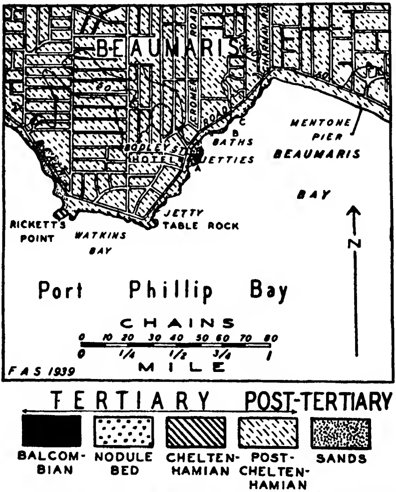

FIG 6.—Geological map of Beaumaris, Victoria Contours from Ringwood sheet, Military Survey of Victoria, 1915.

Beds (iii) to (v) of the section west of the boatshed cannot be recognized here, but the succeeding ferruginous sandstones are evidently represented by bed (*c*), and bed (ix) by bed (*d*).

Since bed (*d*) is probably Pleistocene and bed (*c*) may perhaps be Kalimnan or younger, it seems desirable to restrict the Cheltenhamian to the definitely fossiliferous beds beneath them, down to the nodule bed.

The Cheltenhamian may be defined as the interval of time represented by the deposition of the nodule bed and of the overlying sandstones constituting beds (a) and (b) in the above sequence at Beaumaris, near Cheltenham, as well as those represented therein by non-deposition or erosion.

At the type locality the fauna has been listed by Hall and Pritchard (108, pp. 191-197) and also by Dennant and Kitson (275), who did not, however, separate it from that of the strata below the nodule bed. Other names referring to this section are Cheltenham, Moorabbin, and Mordialloc.

Characteristic mollusca include :—

Pelecypoda: *Limopsis beaumariensis* Chapman, *Neotrigonia acuticostata* (McCoy), *Placunanomia* cf *ione* (Gray)

EYRIAN

This term was first introduced in 1926 by Woolnough and David (652, p. 340) in a vertical stratigraphical section at Muloowurtina, South Australia In it they show 200 feet of strata, overlying the Winton Series of Upper Cretaceous age, and state "Eyrian Series (Tertiary) —Sandy shales. These contain fossil leaves of *Eucalyptus*, &c., in places" In the legend to the accompanying geological map (652, pl. 22) they add "Eyrian Series Mesas of 'Desert Sandstone' with grey Shales, fresh-water. Occasional leaves of Banksia, Eucalyptus, &c. Possibly this Series is Cretaceo-Tertiary," though elsewhere (652, p. 349) they describe it as Older Tertiary to Miocene

It would seem that these authors did not intend to propose a stage name, but only to name a local (even though widespread) series, and it has been used in this sense by E. J. Kenny (32, pp 85-89), who thought the strata in the West Darling district of New South Wales which he referred to the Eyrian Series might "be assigned to the Lower Tertiary, pre-dating at least partially, if not wholly, the period of accumulation of the Marine Tertiaries of the Murray artesian basin."

David (2, table I, opp p. 87), in referring the Eyrian Series provisionally to the Eocene, appears, however, to use it as a subdivisional term comparable to those proposed by Hall and Pritchard for the later marine formations.

The writer (*infra*, p. 51) believes the series may have an extended but perhaps somewhat younger range in time, possibly Oligocene to Miocene, though it must be admitted that the evidence of age is very slender.

It is here suggested that the original usage as the name of a series of strata developed in the Lake Eyre district of South Australia, and not as the name of a stage, be adhered to. The name Eyre Series, comparable with Winton Series, &c., would be preferable to the form Eyrian, but neither term need be further considered here

Gambierian Stage.

This term was introduced in 1916 by Chapman (57, p 381), in referring the lower beds of the Mallee bores of North-West Victoria to "Miocene (Janjukian with a Gambierian facies)," which is stated in a footnote to be "Typically represented by the white polyzoal limestone of Mount Gambier, South Australia" This limestone was, however, placed by Hall (103) with the Balcombian of Muddy Creek, Western Victoria, with which beds Tate and Dennant (185) had also associated it

The name Gambierian was omitted by Chapman from his discussion later in the same paper (57, pp 409, 411) of the subdivisions of the Tertiary beds, and it seems desirable to follow suit and leave the name in abeyance until such time as it may be proved to be a stage in the Barwonian System not comprehended in either the Balcombian or the Janjukian stage.

Giralian Stage.

Proposed herein for the *Discocyclina* limestones between Giralia and Bullara, near the head of Exmouth Gulf, in the North-West Division of Western Australia (fig. 1) These constitute a thin series, 10-30 (?) feet in thickness, resting with a disconformity upon the Cardabia series (Turonian-Campanian) of the Upper Cretaceous, which latter is exposed by erosion of the eastern limb of the shallow Giralia anticline Their relationship to the thick *Lepidocyclina* limestones, probably Upper Oligocene to Lower Miocene, of the Cape Range, some 20 miles to the north-west, is as yet unknown

Since field knowledge (73, 74, 156) of the *Discocyclina* limestones remains virtually restricted to the fact of their occurrence at two localities on the track between Giralia and Bullara, at the northern end of the Giralia Range, and at Red Bluff and Cape Cuvier (78), on the coastline 120 miles to the south-south-west, selection of a type section is not at present desirable.

The Giralian may be defined as the interval of time represented by the deposition of the Discocyclina-*bearing limestones of North-Western Australia, as developed between Bullara and Giralia, as well as those represented therein by non-deposition or erosion.*

The foraminifera of the two localities in the Bullara area have been determined by Chapman and Crespin (306), from whose

identifications the following may be selected as characteristic: *Pellatispira orbitoidea* (Provale), *P inflata* Umbgrove, *Discocyclina pratti* (Michelin), *D dispansa minor* Rutten, *Asterocyclina* cf. *stellata* (d'Archiac), and *Nummulites* sp., the last being recorded only from the second locality, and *Asterocyclina* only from the first

HAMILTONIAN

A term used in 1922 by Mawson and Chapman (640, p 146) in the form Hamiltonian facies, defined in a footnote as "A regional word, here coined to express the combined faunas of the lower and upper Muddy Creek beds with the intercalated limestone of the Grange Burn, ranging from the Balcombian to the Kalimnan."

But the Grange Burn limestone with lepidocyclinae (at that time referred by Chapman to the Janjukian, but by the present writer to the Batesfordian), instead of being intercalated, is actually antecedent to the lower beds (Balcombian of Clifton Bank) at Muddy Creek, as originally maintained by Dennant (83) and since proved by the Muddy Creek bore. The term Hamiltonian can only be used for a system comprising (in terms of the present writer's views as to sequence) the Batesfordian, Balcombian, and Kalimnan stages. It thus overlaps the earlier proposed and better known Barwonian system, and is only a comprehensive term for the whole of the marine Tertiary strata of the Hamilton district, which are referable to stages already defined

It is therefore suggested that the name Hamiltonian is unnecessary and should be abandoned, as has been done, indeed, by Chapman himself

JANJUKIAN STAGE

This, probably the most important stage in point of size, was introduced by Hall and Pritchard (112, pp 78, 79) in 1902, with slightly different spelling, as follows:—" Jan Jucian —The section near Spring Creek, on the coast of Bass Strait, south of Geelong, is in the main in the Parish of Jan Juc, and its fauna differs greatly from that of Balcombe's Bay The township near Spring Creek is called Torquay, but the use of this name in England renders another advisable The older name for Torquay was Puebla, but the employment of this name, again, would lead to confusion with certain American strata The name Jan Juc remains, and is referred to by McCoy as the locality whence several of his fossils came."

The coastal section referred to by Hall and Pritchard extends along Half Moon Bay, in the Parish of Jan Juc, for about 3 miles south-westerly from a point immediately south of Torquay, a township 13 miles south of Geelong, Victoria. The strata form

a broad half-dome whose centre is a few yards south-west of the rock stack known as Bird Rock, from which the lower beds, with a rich molluscan fauna, outcrop near the base of the cliffs opposite, known as Bird Rock cliffs, as far as Fisherman's Steps, about a mile to the south-west.

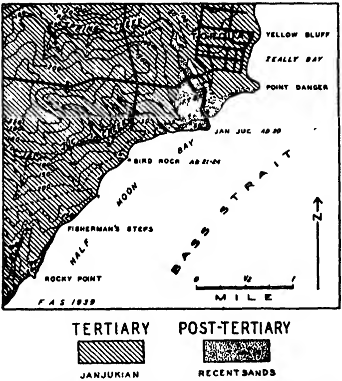

FIG. 7. Geological map of Torquay District, Victoria. Modified in part from Quarter sheet No. 28 S.E., Geological Survey of Victoria, 1863. Contours from Anglesea sheet, Military Survey of Victoria, 1915.

On either limb of the fold the upper beds, chiefly bryozoan limestones with echinoids, &c., are brought down towards beach level by low dips of about 4°–6°, and form on the north-east the cliffs between Bird Rock and the mouth of Spring Creek, and on the south-west those between Fisherman's Steps and Rocky Point, along which cliffs the impure limestones ("echinoderm-rock") are overlain by a younger series of shelly clays.

A good account of the section has been given by Tate and Dennant (183, p. 206; 184, p. 118), who recognized only a division into upper and lower beds, the former including both

limestones and upper clays, and the latter the richly fossiliferous sandy clays and marls, often glauconitic, at or near the horizon of Bird Rock. This was accepted by Hall and Pritchard (107, p. 156), though Daintree, who had first made a twofold division (28), later adopted a threefold division (marginal notes to quarter-sheet 28 S.E., Geological Survey of Victoria, by Daintree and Wilkinson, 1863). More recently Chapman and Singleton (27, p. 994) have described the sequence of the upper beds, and also those in deep borings (27, p 996), while Pritchard (155, p 935) has proposed on palaeontological grounds seven sets of beds. Of these, the present writer identifies the Scutellina Limestones as those of the point and rock stack, immediately south of the mouth of Spring Creek, marked on the military survey map as Jan Juc, a name given on quarter-sheet 28 S.E to the first point north-east of the mouth of Spring Creek, now known as Point Danger, and the Cellepora Limestones as those of the cliffs between the mouth of Jan Juc Creek and Bird Rock Descending stratigraphically, the Ancilla Clays and the Septarian Limestones apparently belong to the upper part of the cliff section, about 180 feet in height, opposite Bird Rock; the Chione clays are regarded as the richly fossiliferous glauconitic clays *above* the hard band which caps Bird Rock; and the Glycymeris beds and the Limopsis beds as the sandy marls *below* the same hard band, which Hall and Pritchard identified (107, p 155) as that dividing Daintree's upper and lower beds The greater part of the fossils listed from the locality, which has variously been termed Spring Creek, Bird Rock Bluff, and Torquay, come from the last three of Pritchard's subdivisions

Since it is hoped in the near future to furnish a detailed account of the stratigraphy and successive faunules of this important section, it is advisable for the present to define the stage in somewhat general terms. It is unfortunate that the cores of the deep borings made by the Torquay Oil Wells Company are unavailable for examination, but an earlier shallow bore reported on by Chapman (267) proved a downward extension of the lower beds of the Bird Rock Cliffs for 70 feet, while Chapman and Singleton (27, p. 996) stated similar greensands and marls to occur at 170 feet below sea level, and it seems reasonable to extend the Janjukian downward to this depth. Pritchard (155, p. 936) claimed a total thickness (inclusive of 183 feet in outcrops) of rather more than 1,000 feet for the marine series, but since lignitiferous sands with *Cyclammina* (here referred to the Anglesean) were reported between 840 and 410 feet below sea level (27, p. 996), much of this cannot be regarded as Janjukian.

The Janjukian may be defined as the interval of time represented by the deposition of the marine beds outcropping in the coastal sections, about 3 miles in length, between Rocky Point

and the mouth of Spring Creek, in the Parish of Jan Juc, and proved in borings to a depth of 170 feet below sea level, as well as those represented therein by non-deposition or erosion

The fauna of the type locality, under the name of Spring Creek, but without subdivision into upper and lower beds, has been listed by Tate and Dennant (183) and by Dennant and Kitson (275) The fossils from the limestones of the upper beds have been recorded by Hall and Pritchard (107, p 162) and those of the upper clays by the same authors (107, p 163) and by Tate and Dennant (183, p 210; 184, p 119)

The characteristic mollusca of the lower beds (below the summit of Bird Rock) include —

Pelecypoda *Limopsis chapmani* Singleton, *Glycymeris (Grandaxinaea) ornithopetra* Chapman and Singleton, *Eotrigonia semiundulata* (Jenkins), *Venericardia janjukiensis* Chapman and Singleton

Gasteropoda *Volutospina anticingulata* (McCoy), *Polinices wintlei* (T Woods).

Less common but apparently restricted species include —

Gasteropoda *Umbilia platyrhyncha* (McCoy), *Pterospira macroptera* (McCoy), *Belophos woodsii* (Tate)

Cephalopoda · *Spirulirostra curta* Tate

KALIMNAN STAGE

This was proposed by Hall and Pritchard (112, p. 78) in 1902 as follows "Kalimnan—The beds at Jimmy's Point, near the mouth of the Gippsland Lakes, are near the township of Kalimna. They were referred to Older Pliocene by Sir F McCoy, and by Mr Dennant to Miocene"

The sandy clays and associated shell beds of the type locality, Jimmy's or Jemmy's Point, also referred to as Kalimna, in Eastern Victoria, have been briefly touched upon by Dennant (85) and by Dennant and Clark (90), but hitherto have not been described in detail A natural section, not more than 10 feet in height, is given by the low cliffs which extend from Kalimna Hotel jetty eastwards for three-quarters of a mile past Jemmy's Point to the bridge which connects the latter with Lakes Entrance township.

The sequence of the strata at Jemmy's Point is well shown by the cuttings along the road which joins this bridge across the North Arm with the township of Kalimna. In stratigraphic order from above downwards it is as follows.—

(*m*) 20 + feet light grey and reddish sands.
(*l*) 30 feet reddish brown clayey sands, with stratification and sporadic pebbles.
(*k*) 4 inches pebble band, discontinuous, including rhyolite pebbles.
(*j*) 8 inches carbonaceous layers in fine sandstone.
(*i*) 3 feet foraminiferal silt

(*h*) 1 foot upper shell bed, somewhat irregular and thinning out to W
(*g*) 1 foot 6 inches hard laminated sandstone
(*f*) 13 feet sandy marls with concretionary bands
(*e*) 4 inches hard band.
(*d*) 13 feet sandy marl and concretionary sandstones
(*c*) 2 feet lower shell bed, sandy marl with *Eucrassatella*, etc.
(*b*) 2 feet 6 inches concretionary sandstone with a few *Turritella* near top
(*a*) 3 feet 6 inches fine sandstone to base of section, about 2 feet above high water mark

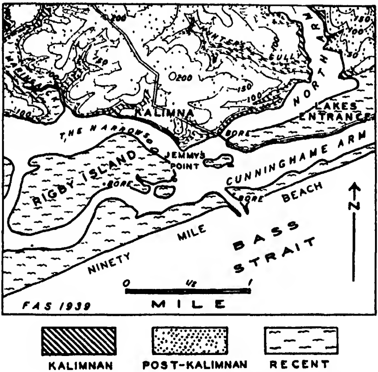

Fig 8.—Geological map of Kalimna district, East Gippsland, Victoria. Modified from geologically coloured and contoured parish plan of Colquhoun, Geological Survey of Victoria, 1929.

Pebbles, though very rarely present in the upper shell bed (*h*), are common on the unfossiliferous beds which succeed the silt bed (*i*), in which W. J. Parr has recognized abundant *Nonion victoriense* (personal communication), and which is here taken as the upward limit of the Kalimnan at this locality. Beds (*j*)–(*m*) are therefore believed to be an Upper Pliocene or Pleistocene series, probably non-marine, resting disconformably on the Kalimnan strata (*a*)–(*i*). Macro-fossils are almost

entirely confined to the shell beds (*c*) and (*h*) and to the upper part of (*b*), but are known to occur in depth in No. 1 Government Bore, Parish of Colquhoun (No. 3, Lakes Entrance), situated at about 9 feet above high water mark, near the north-western end of the bridge. This bore (25, p. 13; 38, p 89) showed the Kalimnan strata to persist, with a rich fossil zone about 10 feet thick, first met with at 90 feet, down to a depth of 140 feet, being underlain by pre-Kalimnan Tertiary strata till the granitic bedrock is reached at 1,404 feet

It is reasonable to add to the exposed Kalimnan strata (*a*)–(*i*), totalling 40 feet, a further 133 feet proved in the bore, giving a total of 173 feet of Kalimnan beds at the type locality

The Kalimnan may be defined as the interval of time represented by the deposition of the sandy marls and sandstones constituting beds (a)–(i) in the above sequence at Jemmy's Point, Kalimna, together with similar beds down to 131 *feet below sea level, proved by boring at this locality, as well as those represented in the preceding by non-deposition or erosion*

At the type locality the foraminifera have been identified by Parr (339), and the mollusca and a few other groups listed by Dennant (85), with subsequent alterations and additions (90) The records by Dennant and Kitson (275) are not confined to Jemmy's Point, in the fauna of which there remains a substantial undescribed residue

Characteristic species of foraminifera, which occur throughout the outcropping beds, are *Glandulina kalimnensis* Parr, *Planulina kalimnensis* Parr, *Nonion victoriense* Cushman, *Flintina intermedia* (Howchin)

The characteristic mollusca of the lower shell bed (*c*) are:—

Pelecypoda *Cucullaea praelonga* (Singleton), *Glycymeris* (*Veletuceta*) *paucicostata* Pritchard, *Ostrea arenicola* Tate, *Neotrigonia howitti* (McCoy), *Chlamys asperrimus antiaustralis* (Tate), *Anomia tatei* Chapman and Singleton, *Venericardia trigonalis* (Tate), *Eucrassatella kingicoloides* (Pritchard), *Clausinella* (*Placamen*) *subroborata* (Tate), *Notocallista* (*Striacallista*) *submultistriata* (Tate), *Bassina paucirugata* (Tate)

Gasteropoda *Turritella* (*Colpospira*) *conspicabilis* Tate, *Tylospira coronata* (Tate), *Polinices* (*Conuber*) *cunninghamensis* (Harris), *Merica wannonensis* (Tate), *Nassarius crassigranosus* (Tate).

In the upper shell bed (*h*) the characteristic mollusca are:—

Pelecypoda· *Nucula* (*Ennucula*) *kalimnae* Singleton, *Nuculana* (*Scaeoleda*) *crassa* (Hinds), *Glycymeris* (*Veletuceta*) *paucicostata* Pritchard, *Neotrigonia howitti* (McCoy), *Clausinella* (*Placamen*) *subroborata* (Tate), *Aloidis* (*Notocorbula*) *coxi* Pilsbry.

Gasteropoda *Bankivia howitti* Pritchard, *Leiopyrga quadricingulata* Tate, *Polinices* (*Conuber*) *cunninghamensis* (Harris), *Merica wannonensis* (Tate), *Nassarius crassigranosus* Tate.

Murravian Stage or System

The first use of the term Murravian appears to have been in 1878 by Tate (171, p 123), who listed the corals of the River Murray cliffs under the heading "Upper Murravian Series." He used the term in the sense of a local series rather than as a stage name, and on the preceding page referred to "the middle and lower Murray series." He also gave a generalized section of the strata of the River Murray cliffs, as follows (171, p. 121):—

"1 Lacustrine (?) sand and marls No fossils, exceeding 60 feet in thickness

2 Upper Marine Series, shelly limestones (false bedded) and oyster beds, with occasional argillaceous and sandy beds Rich in gasteropods and corals About 50 feet thick

3 Middle Marine Series, usually a yellow calciferous sandstone, 40–45 feet thick Rich in echinoderms, brachiopods, pectens, and polyzoa.

4 Lower Marine Series, Ferruginous sandstones and polyzoan limestones Rich in echinoderms and brachiopods, but for the most part of different species to those in the upper beds"

In the following year, Tate repeated this subdivision in a correlation table (47, p. liii).—

"Upper Murravian Shell limestones, oyster beds, and sands
Middle Murravian Calciferous sandstone with polyzoa
Lower Murravian Ferruginous sandstone and polyzoal limestone"

Finally, in 1885, Tate (175) discussed fully the stratigraphy of the Murray River cliffs, illustrated by measured vertical sections at three localities near Glenforslan, 4 miles north from Blanchetown; at North-West Bend Head Station, and at 4 miles south from Morgan. The Upper Murravian was restricted to the oyster banks (characterized by *Ostrea sturtiana* Tate), the underlying beds, with a rich gasteropod fauna at the locality 4 miles south of Morgan, being transferred to the Middle Murravian. Of the Lower Murravian, which is exposed only at the first of the above sections, he remarked (175, p. 41):— "This series is characterized rather by lithological than by palaeontological characters, which latter are somewhat negative, as the species are few in number and somewhat sparsely distributed. It is often highly charged with gypsum, and then fossils are rarely present."

The upper beds, whose fossils are usually poorly preserved, largely as casts, rest in places upon an eroded surface of the middle beds, as at North-West Bend (185, p. 119). These

middle beds, at all events the shelly clays at the locality 4 miles below Morgan, the writer provisionally places in the Balcombian, a correlation previously implied by Tate (181), though they were referred by Chapman (57, p 411) to the Janjukian The unconformably overlying upper or oyster beds have nearly always been placed (44, 57, 112, 185) in the Kalimnan, but the evidence is by no means conclusive and the beds may well be somewhat older

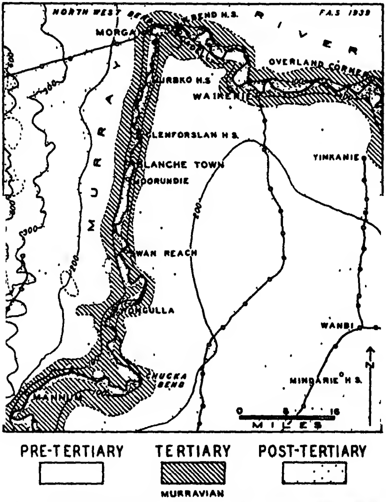

FIG 9—Geological map of part of the Murray River basin, South Australia, Modified from maps of the South Australian Departments of Lands and Mines Contours modified from Adelaide sheet, International Map of the World 1: 1,000,000, and railway heights.

The term Murravian was not considered by Hall and Pritchard (112) in their discussion on nomenclature, and the writer is opposed to its use as a stage or system name for reasons similar to those advanced in respect to the Hamiltonian. Since its use in the form Murravian series has recently been revived by E J Kenny (32, p. 93), it is desirable to give a more precise definition It is difficult to select a single type locality, since at the section 4 miles below Morgan, from which Tate obtained nearly all his fossils, his Lower Murravian is not present, and at other sections where it occurs all the strata are poorly fossiliferous The definition must therefore be in somewhat general terms

The Murravian may be defined as the interval of time represented by the deposition of the marine beds outcropping in the River Murray Cliffs between Blanchetown and North-West Bend, South Australia, as well as those represented therein by non-deposition and erosion

The fauna has been listed by Tate, and the species of the three divisions discussed (175, pp 35-41), while Dennant and Kitson (275) have not distinguished between those of the two lower divisions

Werrikooian Stage

Defined in 1902 by Hall and Pritchard (112, p 77) as follows — "Werrikooian. The Limestone Creek beds on the Glenelg River are in the Parish of Werrikoo, in the County of Follett They have been referred to Pleistocene and to Pliocene There is another Limestone Creek, near the head of the Murray, in Victoria, which yields Palaeozoic fossils, and a third in the County of Heytesbury, with Older Tertiary fossils"

These beds were first described, under the name Bankivia Beds, by Dennant (82, 84), who regarded them as deposited in a former estuary of the Glenelg River, cut through the Ostrea Limestone and the underlying "coralline" [i.e., bryozoan] limestone of Older Tertiary age. The writer (44, 159) has since shown that at the section on the right bank of the Glenelg River in allotment 68, Parish of Werrikoo, known as Caldwell's Cliff, the Werrikooian shell bed rests unconformably on Barwonian bryozoan limestone and is itself conformably overlain by sandy limestones which are capped by the Ostrea Limestone

The localities visited by Dennant occur in the Glenelg River valley in the Parishes of Werrikoo, Killara, and Myaring, and extend from the junction of Limestone Creek to Roscoe's Cliff, in the Parish of Killara, about 3½ miles to the north At none of them is the shell bed satisfactorily developed *in situ*, so that as a type locality Caldwell's Cliff, nearly 2 miles south of the junction, is here selected

BARWONIAN WERRIKOOIAN PLEISTOCENE RECENT

FIG. 10.—Geological map of the Glenelg River valley near Limestone Creek, South-Western Victoria. Modified from geologically coloured and contoured parish plans of Killara, Myaring, and Werrikoo, Geological Survey of Victoria, 1937 8, with additions. Bw Barwonian fossils W. Werrikooian fossils.

[Page 46.]

At this locality, first discovered by J. J. Caldwell of the Geological Survey of Victoria, the sequence measured by the writer is as follows:—

(*m*) 4 feet sandy soil.
(*l*) 2 feet 4 inches oyster bed with *Pecten* (*Notovola*) *meridionalis*.
(*k*) 10 feet 6 inches laminated and cross-bedded limestone with sporadic oysters.
(*j*) 6 feet limestone with abundant irregular concretions.
(*i*) 3 feet 4 inches flaggy limestone.
(*h*) 6 inches oyster band with *Equichlamys bifrons* and mould of *Dosinia*
(*g*) 1 foot 6 inches limestone
(*f*) 8 inches oyster band with quartz pebbles
(*e*) 3 feet limestone.
(*d*) 6 inches oyster band with *Placunanomia*, locally with a 2-inch clayey capping.
(*c*) 8 feet limestone with sporadic oysters and other bivalves (*Placunanomia*, *Glycymeris*), chiefly in a 4-inch grit band 2 feet above its base
(*b*) 1 foot shell bed, resting unconformably on
(*a*) 53 feet bryozoan limestone, largely masked by slip material.

The top 3 inches of bed (*a*), of Barwonian age, is bored by *Barnea*, casts of which may be found *in situ* Bed (*b*), which contains the typical Werrikooian fauna, differs in appearance from the sparsely fossiliferous limestones (*c*)–(*h*) which follow, but the relation is one of conformity, and the same apparently applies to the succeeding beds up to (*l*), which is the well-marked Oyster Bed of the district This latter is referable to the Ostrea Limestone of Dennant (84), but whether beds (*i*)–(*k*) should be included also is debatable

Shell bed (*b*), containing a fauna of 200 molluscan species, with about 5 per cent of extinct species and an extinct genus, is referred by the writer to the summit of the Pliocene, and the succeeding strata may well bridge the boundary of the Pleistocene. For field mapping it is probably best to assume that the beginning of the Pleistocene is marked by the incoming of *Pecten* (*Notovola*) *meridionalis* Tate Provisionally beds (*c*)–(*i*) may be referred to the Werrikooian and beds (*j*)–(*l*) to the conformably succeeding Pleistocene

The Werrikooian may be defined as the interval of time represented by the deposition of the shell bed and sandy limestones constituting beds (*b*)–(*i*) *in the above sequence at Caldwell's Cliff, Glenelg River, in the Parish of Werrikoo, as well as those represented therein by non-deposition or erosion*

The fauna at the type locality as above defined has been studied by the writer, but results are not yet published The original lists given by Dennant (**82**, **84**), based on identifications by Tate, and the slightly amended list of Dennant and Kitson (**275**), all need considerable revision, not only in nomenclature but also because they include a number of extinct species actually derived from the underlying Barwonian (? Balcombian) marls, which outcrop near river level at several localities.

Some of the characteristic molluscan species are as yet undescribed, but the remainder include:—

Pelecypoda: *Nucula* (*Ennucula*) *kalimnae* Singleton, *Nuculana* (*Scaeoleda*) *crassa* (Hinds), *Glycymeris* (*Veletuceta*) cf. *striatularis* (Lamarck), *Chlamys asperrimus dennanti* Gatliff and Singleton, *Zenatiopsis angustata* Tate, *Clausinella* (*Placamen*) *placida* (Hanley).

Gasteropoda: *Bankivia fasciata* (Menke), *Turritella* (*Ctenocolpus*) *terebellata* Tate, *Polinices conicus* (Lamarck).

On the left bank of the Glenelg River at Dartmoor, immediately south of the railway, the following section recalls lithologically the upper part of Caldwell's Cliff.—

(*d*) 14 feet false bedded and thinly laminated limestone, with *Pecten meridionalis* at 5 and 7 feet above base.
(*c*) 5 feet irregularly nodular limestone, with a few oysters at the top
(*b*) 8 inches oyster bed with *Pecten meridionalis* and *Placunanomia*
(*a*) 12 feet flaggy limestones, downward extension obscured by talus down to rail level

At both localities the general sequence is similar and the beds appear to be beach or dune deposits, with a marine incursion represented by the oyster bed This latter, characterized by an oyster which is probably a new subspecies of *Ostrea sinuata* Lamarck, does not occupy the same position in the Dartmoor section, of which beds (*b*)–(*d*) must be referred to the Lower Pleistocene on the criterion suggested above Since the lower part of the section is obscured by talus, it is uncertain if bed (*a*) is underlain by the Werrikooian shell bed.

YALLOURNIAN.

This term was introduced in 1935 by the writer (17, p. 128 and footnote), with the brief statement "Proposed for the lignites and clays of Yallourn."

At Yallourn, in the Parish of Narracan, Gippsland, Victoria, the State Electricity Commission's open cut has exposed 200 feet of lignite overlain by 30 feet of freshwater clays capped by sands.

A deep boring nearby, No. 471, Parish of Narracan (38, p. 144), shows.—

20 feet clay and sand.
237 feet brown coal.
1 foot ligneous clay.
5 feet brown coal.
4 feet ligneous clay.
8 feet brown coal.
48 feet clay.
48 feet brown coal.
20 feet clay.

436 feet depth bored from surface level at 128 feet.

Since, for purposes of correlation, stage names should preferably be based on marine formations, the same objections apply to the Yallournian as to Eyrian, to which, indeed, it may be partially equivalent in time It is therefore best regarded as a series, preferably in the form Yallourn Series, and not as a stage name.

Non-Marine Deposits.

For reasons already indicated the non-marine Tertiary deposits can be discussed in only a very approximate chronological order. The following allocations are thus tentative.

Eocene.

Amongst the earliest non-marine deposits, if indeed they are Tertiary, are the unfossiliferous grey shales, sandy clays and sands, apparently of fresh-water origin, reported between 780 and 1,950 feet in King's Park Bore No. 2, near Perth, by Parr (338), who has referred the overlying series, more than 500 feet in thickness, of foraminiferal shales and intercalated sandstones, to the Upper Eocene But at depths between 1,650 and 1,750 feet in other borings in the Perth area, Miss Crespin has found foraminifera referred to the Lower Cretaceous (338, p. 71), so that while the fresh-water deposits of the King's Park bore are not younger than Upper Eocene, their Tertiary age is not fully established.

Oligocene.

Either Oligocene, or older, are the leaf-bearing pipe-clays of Berwick (238, 240, 636), Narracan (235, 254, 644, 652*a*), and Pascoe Vale (253, 623), which underlie the basalts of the older volcanic series of Victoria, since the basalt of Pascoe Vale may be traced to Royal Park, where littoral marine beds of probably Balcombian age rest on its eroded surface (108, 158). Doubtfully to be placed with them are the "deep leads" (buried fluviatile deposits) of Welcome Rush (45,650) near Stawell, and of the Upper Moorabool River (106, 647) in Victoria, both overlain by marine strata, in the latter case the lower Maude beds of Janjukian age

Probably Oligocene in the main are the important deposits of lignite or brown coal which, in South Australia and more particularly in Victoria, appear to be pre-Barwonian or else contemporary with the earliest marine stages, probably Anglesean. With their associated sands and clays they have been called by the author Yallournian (17), from their development in Gippsland at Yallourn (624) and elsewhere in the Latrobe Valley, in which seams exceeding 500 feet constitute the thickest perhaps in the world.

From their upper part at Yallourn is a florule (245), in which *Banksia* is dominant, occurring sporadically in the lignites, which otherwise contain no plant remains except coniferous wood (200, 202). To the east these beds appear correlable, in their lower portion at least, with the lignites and clays of the deep borings in the Lake Wellington and Lake Victoria district of East Gippsland (Fig 15), which are overlain by the Barwonian marine beds of the East Gippsland region, whose earliest part is above referred to basal Miocene or late Oligocene. Sussmilch (18) has urged that such great total thicknesses of lignite, of the order of 800 feet, indicate that the Yallournian must cover an extended period of time, in his view up to the Lower Pliocene While there is force in his argument that all the lignites are not of the same age, and there is evidence of interdigitation of lignites and ligneous clays with marine beds in bore No. 2, Parish of Nuntin (41), bore No 1, Parish of Goon Nure (40) and bore No. 1, Parish of Boole Poole (41), these latter are probably Anglesean, and it is likely that the bulk of the Yallourn series is pre-Miocene, as are probably the lignites, sands and clays of Altona (23, 108, 638, 648) and Parwan (38), to the north-west of Port Phillip, which are overlain by marine Balcombian, and those of Moorlands (613, 640) in South Australia, overlain by marine Barwonian strata

Approximately equivalent to them in age are the clays and sands at the base of the Point Addis bores (38, p 17), and bores at Dartmoor (38, p 91) on the Glenelg River, in Victoria, and the carbonaceous sands and pipe-clays of Maslin's Bay near Aldinga, in South Australia, in which plant remains occur (236).

Perhaps to be correlated with the Altona lignitic series are the sands, clays, and impure lignite of the Balcombe Bay bore (36, p. 30), likewise overlain by marine Balcombian, but here underlain by basalt

The age of beds containing the so-called "*Cinnamomum* flora," but which do not come into relation with marine deposits, cannot always be established Those of Narracan (235, 254, 644) underlying the "Older Basalt" have above been referred to the Oligocene, and with them may be placed the Elsmore and Vegetable Creek (Emmaville) leads (18, 246), also sub-basaltic, of northern New South Wales, and across the Queensland border the Redbank Plains series (633) near Oxley and Darra, with fish-remains which have been regarded as Oligocene (585). Since the Silkstone series (633) of S.E Queensland, with shales, sandstones, Planorbis limestones, and contemporary basalts, conformably succeeds the Redbank Plains series, it may likewise be provisionally referred to the Oligocene (616).

As elsewhere suggested by the author (17), the *Cinnamomum* flora probably extends, at least in Victoria, from Oligocene to

Upper Miocene, and Sussmilch's view (18) that it, and indeed all the plant-bearing beds, may be referred to the Lower Pliocene, appears untenable (645, 663).

Miocene.

The Eyrian series of lacustrine sandstones and shales, unconformably overlying the Upper Cretaceous Winton series, is typically developed in the vicinity of Lake Eyre in South Australia, but extends into Queensland. Though originally regarded by Woolnough and David (652, p. 349) as "Older Tertiary to Miocene," David later (2) transferred it provisionally to the Eocene. These Eyrian strata in places contain leaves, including *Eucalyptus* and *Cinnamomum*, and Chapman (237) has referred many localities to the lower Oligocene. They may, however, even be Miocene, and it is likely that the Eyrian (or Eyre series) has an extended range in time, perhaps from Oligocene to Miocene, or even later.

The plant-bearing beds (622) and "deep leads" (29, 232, 628) of Eastern Australia probably cover a similar range, but provisionally to be placed in the Miocene are the quartzites with *Cinnamomum* of Dalton (18, 246), near Gunning, and the leaf beds of the Warrumbungle Mts (244) and of the Darling Plains (237) in New South Wales, the sands, clays, and ironstones (28) with *Cinnamomum* which overlie "Older Basalt" at Bacchus Marsh, Victoria; and perhaps the leaf beds of Macquarie Harbour in Tasmania. It must be admitted, however, that the flora shows much resemblance to that of localities such as Narracan, which are above included as Oligocene. Certainly not older than Miocene are the pipe-clays of Sentinel Rock (50, 110) on the Aire coast in Victoria, which overlie marine Barwonian beds and contain a distinctive flora in which *Coprosmaephyllum* and *Persoonia* are common (195, 238, 243).

Elsewhere evidence of age is seldom definite, though occasionally leaf remains are entombed in marine deposits, such as the Plantagenet beds of Cape Riche (271) in Western Australia, and the upper or *Turritella* beds near Table Cape (6, p. 242; 250), Tasmania, both probably lower Miocene, and the upper beds at Beaumaris (17), Victoria, with a latest occurrence of *Cinnamomum* in probably Upper Miocene strata.

In Western Australia non-marine strata attributable to some part of Tertiary time include the lacustrine clays and basal grits and conglomerates (7), totalling at least 100 feet in thickness, which rest unconformably on the Permo-Carboniferous coal measures of the Collie River, in the South-West Division, and are in turn overlain by gritty laterite.

Of Tertiary age, perhaps Miocene or Oligocene, are lacustrine deposits of numerous areas in Eastern Queensland (2, 20), including those of the Baffle Creek basin near Port Curtis and of Duaringa in the Dawson valley, and the lignites of Water Park Creek, north of Rockhampton

Pliocene

Perhaps referable here are the newer deep leads (27, 195) of S.E. Australia and Tasmania (6), in part covered by the newer volcanic rocks and sometimes containing leaves or fruits, as at Haddon (212, 663) in Victoria, Gulgong (18, 206) in New South Wales, and Brandy Creek (210) in Tasmania. Similar in age may be lacustrine deposits of the Derwent (631, 632) and Launceston (629, 630) basins in Tasmania, while in Victoria the "torrent gravels" of East Gippsland (617, 694) are probably late Pliocene and the result of the initiation of uplift in the Eastern Highlands

Though the *Planorbis* limestones of Mt Elder Range (7), in the Kimberley region of Western Australia, have been referred to the Pleistocene (619), their physiographic setting suggests a Pliocene age

In Central Australia the Arltungan (preferably Arltunga) series (639), perhaps late Tertiary to Pleistocene, consists of sands, clays, and gravels, usually as small mesas, often with chalcedonized "duricrust" The series includes *Planorbis* limestone on Paddy's Hole Plain, and limestones with *Corbicula* on the Hale Plain near Claraville, both in the Arltunga district of the Eastern Macdonell Ranges

Over much of the interior of the continent silicified or otherwise indurated superficial deposits, which have been termed "duricrust" (705), belong to some part of Tertiary time. Somewhat similar, in Eastern Australia, are the silicified sands or "grey billy" (645) of ancient river deposits, perhaps Pliocene, whose silicification is commonly ascribed to overlying basalt, as at Keilor (108) in Victoria, Tallong, Ulladulla and Moruya (614) in New South Wales, and at Bald Hills in S.E. Queensland, where quartzites occur in the Petrie series (633), chiefly quartzite breccias and micaceous sandstones of late Tertiary age.

Tentatively to the Pliocene have been ascribed some of the deep soils, including "red earths" and "red loams," of Queensland (616), and some of the plateau soils of New South Wales (615) may be similar in age. The older alluvia, sometimes with extinct marsupials, may range back into the late Pliocene, though the majority are more probably Pleistocene.

Igneous Rocks.

In Eastern Australia an earlier volcanic series, chiefly basic, which is developed in south-central Victoria, in north-western Tasmania, in northern New South Wales, and in south-eastern Queensland, is probably chiefly Oligocene, with some members of Lower Miocene age

In Victoria the Older Volcanic series ("Older Basalts"), which at Western Port is more than 1,000 feet in thickness, includes (661) olivine-basalts, olivine-titanaugite-basalts, and crinanites, as well as some limburgites and nephelinites, all of which are also represented in the associated dyke-swarms, together with camptonites and other lamprophyric types The "Older Basalts" are overlain unconformably by marine Barwonian sediments, chiefly Lower Miocene, which include Janjukian limestone at Airey's Inlet (102), Batesfordian limestones at Flinders (23, 137) and Keilor (77, 108), and Balcombian marls at Balcombe Bay (36, p. 30; 111) and Curlewis (76, 105), and ironstones at Royal Park (13, 70, 108, 158). While these basalts are probably Oligocene or even older, the older basalt of Maude (106), resting on Janjukian limestones and unconformably overlain by Balcombian limestones, must be of Lower Miocene age. In South Gippsland the Older Volcanic series underlies the principal lignite seams of the Yallourn series, as at Warragul (36), Yarragon (624, 648), Yallourn (624), and Boolara (648), but occasionally is underlain by thin lignite seams, as at Yarragon (648), rarely thicker, as at Elizabeth Creek, Allambee East (648), and Narracan (652*a*), or by lignitiferous sands as at Balcombe Bay (36).

Perhaps referable to a similar Oligocene horizon are the basalts overlying the older deep leads at Emmaville (18) and elsewhere in the New England district of New South Wales, and the basalts of the Redbank Plains series and interbedded in the Silkstone series (633) of South-eastern Queensland, as well as the basalt of Marrawah, on the west coast of Tasmania, pebbles of which occur in the adjacent Barwonian bryozoan limestone (10, pp. 25, 26, 50).

The relationship of these older volcanic rocks to beds containing the *Cinnamomum* flora is a varied one. In Victoria at Bacchus Marsh (9, 28) the basalt is the older, but at Narracan (644), Dargo (643), and elsewhere the leaf beds are covered by basalt, a relation also obtaining at Vegetable Creek (Emmaville) (18) in New South Wales and at Redbank Plains (633) in Queensland.

Alkaline lavas and intrusive rocks, perhaps chiefly of late Tertiary age, are developed in all States except South Australia. By some authors they have been regarded as constituting a middle series of eruptions intermediate in age between the older and the newer volcanic series, both dominantly basaltic; others have associated the alkaline rocks with one or the other of these

main series. Though it is tempting to correlate the alkaline rocks and, indeed, David (2) referred most of them to the Pliocene, in many cases the evidence of age is but slight

In Western Australia the leucite-lamproites of the Fitzroy River in the West Kimberley district (677, 684) include plugs and fissure intrusions which are post-Permian and may be of Tertiary age

In S.E. Tasmania the alkaline intrusive rocks of Port Cygnet and Woodbridge (673) are post-Triassic and probably Tertiary They include alkali-syenite-porphyry, foyaite-porphyry, solvsbergite-porphyry, and tinguaite-porphyry, as well as many other types.

In Victoria alkaline rocks are associated both with the Older Volcanic series (Oligocene to Lower Miocene) and with the Newer Volcanic series (late Pliocene to Pleistocene or possibly Holocene), but chiefly with the latter To the former have been attributed (656) the phonolite and tinguaite which form pipes and dykes near Harrietville (674) in N.E. Victoria; to the latter belong the alkaline volcanic rocks of the Macedon district (659, 679) in Central Victoria, perhaps in part Upper Pliocene, including solvsbergite, anorthoclase-trachyte, anorthoclase-basalt, oligoclase-basalt (macedonite), woodendite, and limburgite Trachytes and trachyphonolites or phonolites also occur near Trentham in Central Victoria, near Casterton in South-West and Omeo in North-East Victoria

In New South Wales alkaline rocks, both extrusive and intrusive, are widespread and have been associated (653) with the older basic series, probably Oligocene to Miocene, but by others have been placed later (2, 681) They include the comendites, trachytes, trachyandesites, and tuffs of the Canobolas Mountains (682) near Orange, the trachytes and phonolites of the Warrumbungie (665) and Nandewar Mountains (666), the comendites and anorthoclase-trachytes of the Lansdowne Plateau (653) near Taree, and the tinguaite laccoliths of the Barigan district (653).

Similar alkaline rocks occur in S E Queensland (671), notably the trachytes and tuffs of the Main Range, Fassifern district, and Mount Flinders (669), and the plugs and flows of the Glass House Mountains (664), including pantellerites, comendites, trachytes, and dacite. In Central Queensland the volcanic rocks of Springsure (670) include trachyte, trachyte tuff, and phonolite in their middle portion.

The Newer Volcanic series of south-western and central Victoria, though including Pleistocene and perhaps Recent members, was initiated at a period variously regarded as late (17), middle (663), or early (18) Pliocene or even older (650). The earliest flows in the Western District of Victoria appear, however,

always to be post-Kalimnan, though their relation to the Werrikooian is not fully clear. The Drik Drik basalt has been regarded as pre-Werrikooian (18, p. xxii); those of the Portland district, which may be younger, overlie oyster beds (82, p 230; 84, p. 446) which the writer (159) has correlated, though not on very secure grounds, with those conformably overlying the Werrikooian shell beds of the Glenelg River In any case the Tertiary members of the Newer Volcanic series can be regarded as not older than Middle Pliocene, at least in South-west Victoria

Petrographically (659) they are chiefly olivine-labradorite-basalts, but limburgitic and alkaline types occur Some of the latter have already been mentioned; of the others, in many instances, the age is post-Tertiary

Probably to be correlated with the Newer Volcanic series of Victoria are the olivine-basalts of Tasmania (660), best represented on the north-west coast, where they overlie marine Janjukian near Table Cape (131). They also overlie the lacustrine deposits of the Launceston Tertiary basin, and may largely be Pliocene

In New South Wales a newer basic series of lavas and intrusive rocks has been regarded as largely early Pliocene in age (653, 681). Though known as far south as Moruya (21), the lavas are best developed in the northern part of the State, notably in the New England district. They are largely olivine-basalts, but include andesitic basalts with little or no olivine, as well as alkaline types such as nepheline-basalts and leucite-basalts, and also, in the extreme north, acid pitchstones

In South-east Queensland an upper division of volcanic rocks (669, 671), largely basic, may be Pliocene, at least in part They are chiefly olivine-basalts, but andesites and andesitic basalts also occur Beneath the basalts or intercalated with them at the Springbrook Plateau (653, p 30) are rhyolites and pitchstones which may belong to the same series, though Richards (669) had regarded the acid lavas and agglomerates of the Macpherson Range (653, p. 30; 671, p 295; 681, p. 44) as contemporaneous with the trachytes elsewhere.

Basaltic rocks occupy large areas in Central and Northern Queensland, but may in part be post-Tertiary (671, p. 298), since volcanic activity appears to have persisted, as in Victoria, up to Recent times.

In contrast to the olivine-basalts of Victoria are the tholeiites (658) of Western Australia, occurring in the extreme south-west in isolated areas from Bunbury to Cape Gosselin (657) and the Donnelly River. Being antecedent to the Coastal Limestone, which is probably Pleistocene, they may provisionally be referred to the Pliocene.

Diastrophism and Palaeogeography.

Following the recession of the Cretaceous seas, which occupied much of the interior of Australia in Upper Albian time (Tambo series of Queensland and South Australia), and persisted till Santonian and even Campanian time (Cardabia series) in Western Australia (156), the greater part of the continent appears to have been undergoing denudation in early Tertiary time, and marine Eocene deposits are confined, so far as is known, to the extreme north-west and perhaps the south-west

There is, however, no agreement as to the degree of completion reached by the erosion cycle initiated by the uplift in late Cretaceous or epi-Cretaceous time, which in Queensland was associated with the folding of strata of Albian to Cenomanian age (Burrum and Styx coal-measures). David (2) believed that in Eocene times almost the whole of Australia was a nearly perfect peneplane, while Fenner (689, 690) thought that even in the earliest Eocene the land area might have been very low and level, and in any case by the end of the Oligocene must have developed a high degree of peneplanation, a view accepted by Lewis (690) and by Nye and Blake (10) for Tasmania.

On the other hand, Denmead and Bryan (690) considered that in Eastern Queensland, following a late or epi-Cretaceous orogeny, considerable surface relief (691) was present in Eocene and Oligocene times, instead of a well developed peneplane in the late Oligocene For New South Wales, Sussmilch (18, 690), and for Victoria, Hills (696), agreed that a Cretaceous peneplane had suffered a late or epi-Cretaceous epeirogenic uplift estimated by the former as 450 to 1,500 feet, and by the latter as more than 2,000 feet. They thus picture tablelands at the commencement of Tertiary time, out of which, according to Sussmilch, an erosion cycle carved by the end of the Miocene a younger or Great East Australian Peneplane, a concept earlier put forward by Andrews (685). Hills (690), however, believed that in Victoria mature dissection of the elevated highland region had occurred by Oligocene times, when the Older Volcanic series was first extruded, but that no well developed peneplane was formed, though flat areas were present notably in the plain tracts of the streams.

In Western Australia, Jutson (690, 700), though allowing the possibility of uplift at the close of the Cretaceous followed by an early Eocene dissection, postulated the reduction of the whole State by post-Cretaceous erosion to a vast plain, probably chiefly by peneplanation, but perhaps marginally by marine abrasion. Since marine Miocene deposits rest on these marginal areas, the planation was regarded as completed by Oligocene or perhaps very early Miocene times.

It is evident that physiographers show a measure of agreement in regard to an early Tertiary erosion cycle following on a probably epi-Cretaceous uplift, but that there is disagreement as to whether this cycle achieved completion by the beginning of the Miocene. It may well be that both views are in some degree correct: that in part, notably in the western half of the Continent, peneplanation was further advanced than elsewhere, while in portions at least of Eastern Australia the more elevated regions had not yet been reduced by erosion. If the older volcanic rocks of South-Eastern Australia are correctly referred to the Oligocene, the topography, though mature, was by no means a peneplane.

If we turn to the evidence of marine sedimentation, we find that the Upper Eocene deposits of North-West Australia and the Upper Cretaceous Carbadia series show marked parallelism of attitude and that both have been folded together (156). But since the highest Cretaceous horizon recorded is probably Campanian, and Paleocene to Middle Eocene beds are as yet unknown, it would appear that the relation is one of disconformity, marking a retreat of the late Cretaceous sea before its readvance in the Upper Eocene (Giralian). Since the date of reading of this paper Spath's recognition of a Maestrichtian fauna (*Journ. Roy. Soc. W. Aust.*, vol 26, 1940, in press) has been reported by Teichert (703), who regards the Tertiary sequence as conformable to the Cretaceous. The extent of this transgression in the North-West Division of Western Australia remains uncertain, since the evidence of an eastward extension of the Eocene sea to Merlinleigh, 115 miles inland from the present coastline, afforded by the discovery of *Aturia* cf *ziczac* (569), is vitiated by a doubt as to whether the specimen may not have been transported there by human agency.

The next marine horizon recognized in North-Western Australia is not older than Upper Oligocene, so that there may have been a recession and readvance of the sea in this area. This may also be the period of first marine transgression at the head of the Great Australian Bight, in the Murray basin and along the southern coast of Victoria (Anglesean).

The downwarping which allowed of this was apparently the aftermath of movements of sag (perhaps accompanied at their initiation by volcanic activity), which had permitted the accumulation in Oligocene times of a thick Yallourn series of lignites, sands, and clays in a basin or basins extending in Southern Victoria from the Parwan-Altona area, south-west of Melbourne, easterly past Morwell and the Latrobe Valley nearly to Sale. Whether part of the Yallourn series of non-marine deposits was contemporaneous or penecontemporaneous with the earliest stages of marine transgression (Anglesean ?) in the East Gippsland basin is uncertain, but at all events no thick seams of brown coal

are known to overlie marine Barwonian deposits, while the reverse is frequently the case. There is evidence of some oscillation of the Oligocene shoreline, given by deep bores near Lakes Wellington and Victoria (*infra*, p. 81 and fig. 15).

By the beginning of the Miocene, embayments of the Janjukian sea were already well established in South-eastern Australia, notably in the East Gippsland, South Central and South Western areas of Victoria, and in the Murray Gulf which extended from Aldinga in South Australia, across the site of the present Mt. Lofty ranges, into the Mallee district of North-west Victoria (Mount Gnarr bore (57), 754 feet) and into New South Wales (South Ita bore (134), 420 feet), more than 200 miles inland from the present coastline. In North-west Tasmania the littoral "Crassatella" grits, in places conglomeratic, near Table Cape, laid down in the transgressive phase of the Janjukian sea, contain a fauna closely comparable with that of fairly shallow water but not littoral deposits of the type locality near Torquay in Victoria, with which area the sea was doubtless continuous. At Table Cape the overlying Turritella beds (sandy clays) constitute the succeeding shallow water phase of a cycle of sedimentation which is very incomplete. Approximately at the same time a continuance of sagging movements at the head of the Bight resulted in development of what Jutson (700) has termed the Eucla Gulf, nearly to 200 miles north of the present coastline.

Continued sinking, aided by the reduction of relief due to the early Tertiary erosion cycle, resulted in a maximum transgression, in late Lower Miocene and Middle Miocene times (Batesfordian and Balcombian), of seas in which accumulation of limestones was favoured by the reduction of terrigenous material from the diminished and low-lying land areas. In Victoria the chief basins of sedimentation were, as already noted, in East Gippsland from Orbost to Woodside, in South Central and South-Western Victoria, probably continuous beneath the basalt cover of the Western District, and that portion of the Murray Gulf represented by the Wimmera and Mallee districts of North-west Victoria. These three main areas were partially separated by the Palaeozoic or older rocks of Wilson's Promontory and of the Dundas area respectively. Since the deposits of the Murray Gulf are known chiefly from borings, no definite delimitation of its boundaries can be made, but the northern limit is at least as far as lat. 32° 38′ S. (Buckalow bore (134)) and may be set by the ancient rocks of the Barrier Ranges near Broken Hill, while to the east, marine Tertiary deposits are known in New South Wales in long. 142′ 55° E. (Arumpo bore (94)) and borings in Northern Victoria suggest a boundary in approximately the same longitude (697, p. 299). Towards the outlet of the Gulf an upwarp, probably Pleistocene, has caused the Murray River to expose marine Barwonian (in part Balcombian ?) and overlying Kalimnan (?)

strata in cliff sections from near Overland Corner almost to its exit into Lake Alexandrina Southerly from these sections borings in the Murray Plains (123) suggest that the Murray Gulf continued down to the Mount Gambier district in the south-east of South Australia, and the deposits of this area are probably continuous with those exposed in the cliffs of the lower Glenelg River in South-Western Victoria

No evidence of Miocene seas is available along the eastern coastline of Australia, since in these regions subsidences in late Tertiary time (2, p 174) have left the deposits beneath sea-level and inaccessible to observation In the south-west, however, the occurrence of marine Miocene deposits on the surface of the Western Australian peneplane (?), as far north as Norseman, 120 miles inland, is evidence of a considerable submergence (690, p 467, 693; 700; 701), while in the north-west submergence in Miocene times, perhaps from slightly earlier than Batesfordian into probably Balcombian times, is indicated by limestones from near North-West Cape southwards to Carnarvon

Although the Tertiary rocks are commonly either horizontal or very gently tilted, highly dipping and even vertical strata are known where they have become involved in fault movements, as on the coast near Sellick's Hill (698) in South Australia, at Longford (183, p 210), near Sale, and at Waurn Ponds in Victoria, where Janjukian limestones have been sharply flexed in a very asymmetric syncline with one perpendicular limb. Folding of Janjukian strata has occurred, however, at the type locality near Torquay (183, 686), where a denuded half-dome shows dips of about 10°, and on the Aire coast, where there is gentle folding (110), with dips of 40° off the Jurassic rocks at Castle Cove The Balcombian clays and limestones of the type locality of Balcombe Bay show dips of up to 20° and slight contortion of strike (111), and those of Grice's Creek much higher dips, which are attributable to landslips or faulting At Curlewis, however, folding and faulting (23, 76, 105) occur in strata here assigned to the Balcombian, and at Beaumaris (108, p 190) a monoclinal or asymmetric anticlinal fold, with a maximum dip of about 25°, is developed in strata not older than Upper Miocene (Cheltenhamian) The date of this folding is uncertain, and may be as late as Upper Pliocene

In Queensland the orogeny in which strata perhaps as young as Cenomanian have been strongly folded, and regarded by some as epi-Cretaceous (690, p. 470), has been claimed to be Tertiary in age (702, p. 306). In any case folding of Tertiary lacustrine deposits, with dips up to 45° at Baffle Creek, appears to be established (702, p 309).

In the North-west Basin of Western Australia open folding, in which marine beds from Upper Eocene to Miocene are involved,

has been referred to the late Miocene or Pliocene (67, 74, 156). The folds trend from 10° to 25° east of north and the anticlinal members, of which the Cape Range, Rough Range, and Giralia Range anticlines are the chief, form topographic ridges more or less dissected by stream erosion. Though dips are low, being from 2° to 8°, the large size of the structures, in the case of the Cape Range anticline 25 miles in width and 100 miles in length, has caused marine Tertiary rocks to be elevated to 1,200 feet above sea level Since the underlying Upper Cretaceous beds (Cardabia series) are folded with the Tertiary strata, it is believed that no marked structural deformation occurred during early Tertiary time, followed, according to David (2, p. 19) by post-Miocene folding due to easterly directed thrusts from the Indian Ocean

In South-East Australia sagging movements continued through Upper Oligocene to Middle Miocene time, permitting accumulation of marine marls and limestones, under shallower bathymetric conditions, perhaps 15 to 30 fathoms, than previously (27) suggested, to considerable thicknesses, over 2,500 feet at Lake Kakydra (41, p 35) near Sale, in the centre of the East Gippsland basin, and over 2,000 feet at Portland (57, p 401) in South-west Victoria In the Sorrento bore (63) in the Port Phillip area the corresponding thickness is about half this latter amount, and probably the same is true of the Murray Gulf

By Upper Miocene times (Cheltenhamian) this downward movement had already been arrested, and may have been reversed, and by the Lower Pliocene the Kalimnan seas were shallower, perhaps 10 to 15 fathoms in depth, and probably considerably restricted in extent, though it is difficult to draw exact boundaries The dominant lithological types are fine sands and sandy clays, with an absence of pure limestones. Evidence of a break in sedimentation is afforded by slightly phosphatic nodule beds at the base of the Kalimnan at Grange Burn in the Hamilton district, and elsewhere, and at the base of the Cheltenhamian at Beaumaris

In the Middle Pliocene the grey sands and shelly fauna of the Adelaidean alike suggest shallow water conditions, perhaps 5 or 6 fathoms in depth, but their geographic distribution is limited to the vicinity of Adelaide on the north and west The fauna is rather closely related to that of the Kalimnan, and though it may perhaps be present in the Sorrento and Mallee bores, the Adelaidean stage has not been recognizable with certainty outside the type area The filling up of the Murray gulf by clastic sediments may have been accompanied by a draining back of the shallowing sea as a result of initiation of upwarp movements in the later Pliocene. At all events towards the close of the Pliocene definitely marine conditions had disappeared from the greater part of the Murray basin, and Werrikooian seas, in which shallow

water and even sub-littoral shell beds and sandy limestones were accumulated, were largely restricted to the extreme south-west of Victoria, adjacent areas in South Australia, and perhaps a former estuary near Tintinara (57, p 400; 68; 123, p. 185; 179) on the lower Murray plains. The final elevatory movements which drained this Werrikooian sea were post-Tertiary and thus outside the scope of this survey

There is no unanimity as to the interpretation of the terrestrial record of Miocene and Pliocene times. Woolnough (704, 705) believed the lateritic duricrust of Western Australia was formed during a period, which he regarded as approximately Miocene, of extreme peneplanation, but this conception has been criticized by Clarke (690. p. 467). This surface, which is the "Great Peneplain of Western Australia" of Jutson (700), was thought by him (690, p. 469) to have suffered uplift, commencing in the late Miocene or early Pliocene and interrupted by several intervals of stillstand, during the first of which, in the Pliocene, the wide valleys of the Meckering Level were excavated. Subsequent elevatory movements, probably successive, with warping and some faulting, and chiefly also Pliocene, were thought to have given rise to the present Westralian plateau

Fenner (688, 689) not only postulated for much of Australia an epi-Miocene gradual uplift, passing in the Pliocene into heavy block faulting and differential uplift, but also tentatively suggested a late Pliocene stillstand with peneplanation in South Australia While a period of Pliocene stillstand has been supposed for part of Western Australia, as above noted, it was not long enough for peneplanation, though broad valleys were cut Nor has the hypothesis of late Tertiary peneplanation, though apparently adopted by David (2, p 91), proved acceptable for Tasmania (690, p 471) although Lewis (692, p 401) postulated a late Tertiary peneplain, elevated to 1,400 feet in late Pliocene times, or for Victoria (690, p. 474), where, however, post-Miocene erosion has truncated a fold in Cheltenhamian rocks at Beaumaris.

The period of epeirogenic uplift, with accompanying warping and block-faulting, which initiated the present erosion cycle, was placed at the end of the Pliocene and termed the Kosciusko Period by Andrews (685), who regarded the movement as dislocating a surface with broad shallow valleys These wide, mature "Upland Valleys" of New South Wales were believed by Sussmilch (18; 690, p. 465) to have been cut during a cycle initiated by an epi-Miocene uplift of the order of 400 feet There is no general agreement as to whether the period of maximum uplift (Kosciusko epoch) should be regarded as early Pleistocene (685; 689, p. 471) or as late Pliocene (2, 18), which latter is probable in Victoria (695).

Conclusion.

Correlation within Australia.

The writer's views on correlation within Australia are summarized in the accompanying table. Since he believes that only the broadest correlations are possible with Tertiary deposits in distant parts of the world, and that while even internal correlations are not yet satisfactorily established, it is impracticable to equate local stages with those of Europe, the reference in the correlation table to subdivisions of the major European units is a tentative one. For this reason the use of a local nomenclature for stages is important, as has been proved in the parallel case of New Zealand, and its partial discontinuance by some Australian authors is to be deplored as a retrogressive step, tending towards that confusion which the local names were designed to reduce.

Should it be proved, as is probable, that stages exist which are not covered by the names already proposed, further stage names should be introduced, provided they are rigorously defined.

Correlation with the East Indies.

The studies of the larger foraminifera which have already been made enable a provisional correlation with the stratigraphic divisions established by the Dutch geologists in the Netherlands East Indies. Most of this work in Australia has been done by Chapman and by Miss Crespin, whose correlations differ in part from those made elsewhere in this paper and here summarized:—

Europe	East Indies	Australia
Miocene	*g*	
	f	Balcombian marls with *Trillina howchini*. Muddy Creek (Clifton Bank) and Mitchell River (Skinner's), Victoria. Limestone with *Trillina howchini*, *Flosculinella bontangensis*, *Lepidocyclina*, &c. Cape and Rough Ranges, Western Australia. Batesfordian limestones with *Lepidocyclina* cf. *tournoueri* and *L. verbeeki*. Batesford, Keilor, Hamilton bore (Muddy Creek), &c., Victoria.
	e	Limestone with *Lepidocyclina murrayana*, *L. verbeeki*, &c. North West Cape Range, Western Australia.
Oligocene	*d*	Limestone with *Lepidocyclina dilatata*, *L. papuanensis*, &c. North West Cape Range, Western Australia.
	c	
Eocene	*b*	Giralian limestone with *Discocyclina* and *Pellatispira*. Giralia Range, Western Australia.
	a	

TENTATIVE CORRELATION TABLE OF THE TERTIARY ROCKS OF THE COMMONWEALTH OF AUSTRALIA.

			Marine Stages	Western Australia. Marine	Western Australia. Non-Marine	South Australia. Marine	South Australia. Non-Marine	Victoria. Marine	Victoria. Non-Marine	Tasmania. Marine	Tasmania. Non-Marine
PLIOCENE	UPPER		WERRIKOOIAN		? Laterites developed superficially. Cherts of Mount Elder Range with *Planorbis hardmani*. ? Tholeiitic basalt of Bunbury.	? Tintinara bore.	? Arltunga series of Central Australia, sands, clays, and gravels, often with "duricrust," and freshwater limestones in Arltunga district, Eastern MacDonnell Ranges. Silicified "duricrust" of the interior of Australia, in part.	Ostrea limestone of S.W. Victoria, in part. Shell beds of Glenelg River, Moorabool Viaduct, Sorrento and Mallee bores	Turreot gravels of East Gippsland. ? Earliest flows of Newer Volcanic series (basalts, &c.) ? Alkaline volcanic rocks of Macedon, in part	? Wingaroo bore, Flinders Island	? Basalts of North West Coast
	MIDDLE		ADELAIDEAN		?? Alkaline volcanic plugs of Kimberley Division.	Shelly sands of Dry Creek, Abattoirs, and other bores near Adelaide			Younger "deep leads" with fossil fruits at Haddon, &c.		Sub-basaltic leads with fossil fruits, Brandy Creek, &c. ? Lacustrine beds of Launceston and Derwent Basins.
	LOWER		KALIMNAN			? Upper beds of Murray River cliffs and at Aldinga		Sands and marls of East Gippsland, Muddy Creek (upper beds), upper part of Sorrento, Mallee and Wimmera bores			
MIOCENE	UPPER		CHELTENHAMIAN	? Limestone of W. side of North-West Cape Range.		? Shell beds in well-sinking at Mindarie		Sands, marls of upper beds at Beaumaris. ? Middle part of Sorrento bore. ?? Shell marls of coastal cliffs near Sherbrook River	Leaf beds overlying marine Barwonian at Sentinel Rock and (?) Pitfield Plains. Sands, clays, and ironstones with *Cinnamomum* at Bacchus Marsh		?? Alkaline intrusive rocks of Port Cygnet and Woodbridge
	MIDDLE	BARWONIAN SYSTEM	BALCOMBIAN	Limestone with *Flosculinella* and *Trillina howchini* of Cape and Rough Ranges and Carnarvon bore.	? Lacustrine clays, sands, and conglomerate of Collie River Valley	Middle beds of Murray River cliffs near Morgan. ? Bryozoan limestone of Mount Gambier		Shell marls of Mornington, Muddy Creek (lower beds), Fyansford, Barwon Basin, Gellibrand, Mitchell River, and lower part of Sorrento bore. Limestone of upper beds at Maude. Ironstones of Keilor and Royal Park (lower beds).		? Bryozoan limestone near Cape Grim and on Flinders and King Islands.	
	LOWER	BARWONIAN SYSTEM	BATESFORDIAN	Limestone with *Lepidocyclina murrayana* and *L. verbeeki* of North-West Cape Range.			? Eyre series, sandstones with plant remains, of Lakes Eyre and Torrens	Lepidocyline and bryozoan limestones of Batesford, Keilor, Flinders, Muddy Creek bore, and East Gippsland bores.	"Older Basalt" of Maude.		
		BARWONIAN SYSTEM	JANJUKIAN	Plantagenet beds (siltstones) of Albany and Cape Riche. ? Limestone of Lake Cowan district near Norseman. Eucla limestone of Great Australian Bight.		? Limestones beneath Nullarbor Plains. ? Lower beds of Aldinga and in Adelaide bores.		Shell marls and bryozoan limestones of Torquay. Limestone of Waurn Ponds and Maude (lower beds). ? Marls and limestones of Aire coast and clays of Cape Otway	? Deep leads with fossil fruits at Hoddle's Creek and Tanjil. ?? Upper part of Yallourn series	"*Crassatella*" and *Turritella* beds of Table Cape.	? Leaf beds of Macquarie Harbour
OLIGOCENE	UPPER		ANGLESEAN	Limestone with *Lepidocyclina dilatata* and *L. papuanensis* of North-West Cape Range. ? Lower part of limestone in bores on Eucla Plateau.		? Lower beds of deep bores near Mount Gambier	Sands and pipeclay with leaves, Maslin's Bay, Aldinga. Lignites and leaf beds of Moorlands.	Carbonaceous sands with *Cyclammina* of Anglesea Cliffs, Torquay bore (410–840 feet), and near base of bores in East Gippsland, Mallee (Tiega bore), and Dartmoor.	? Yallourn series, lignites, sands, and clays of Morwell and Yallourn. Sands, sandy and ligneous clays beneath marine marls in Balcombe Bay bore, sands, clays, and lignite beneath Balcombian at Altona to Parwan (bores). Lignite and clays of Goon Nure bore, East Gippsland, sands and clays at base of Point Addis, Dartmoor, and Mallee bores		Basalt of Marrawah
EOCENE	UPPER		GIRALIAN	*Discocyclina* limestone of Giralia Range and Cape Cuvier, N.W. Division. ? Foraminiferal shales of Perth District, between 120–770 feet in King's Park bore No. 1.	? Freshwater sands and clays between 780–1,950 feet in King's Park bore No. 2.				Older Volcanic series (basalts, &c.) of Western Port, South Gippsland, &c. Leaf-beds of Berwick, Narracan, Pascoe Vale, &c. ? Deep leads of Stawell and upper Moorabool River.		

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VICTORIA. Marine	VICTORIA. Non Marine	TASMANIA. Marine	TASMANIA. Non-Marine	NEW SOUTH WALES. Marine	NEW SOUTH WALES. Non-Marine	QUEENSLAND. Marine	QUEENSLAND. Mom-Marine
Ostrea limestone of S.W. Victoria, in part. Shell beds of Glenelg River. Moorabool Viaduct, Sorrento and Mallee bores	Torrent gravels of East Gippsland ? Earliest flows of Newer Volcanic series (basalts, &c.) ? Alkaline volcanic rocks of Macedon, in part.	? Wingaroo bore, Flinders Island	? Basalts of North West Coast		? Plateau soils, in part. Newer volcanic series (basalts), in part. Sands, gravels, and "grey billy" of Hunter River Valley, South Coast, &c.		? "Red loam" and "red earth" residuals. ? Rhyolites and basalts of South East Queensland. ? Petrie series of sandstones, quartzite, &c
	Younger "deep leads" with fossil fruits at Haddon &c		Sub basaltic leads with fossil fruits, Brandy Creek, &c. ? Lacustrine beds of Launceston and Derwent Basins	? Ferruginous grits of Moruya.	Sub-basaltic leads of Gulgong with fossil fruits.		
Sands and marls of East Gippsland, Muddy Creek (upper beds), upper part of Sorrento, Mallee and Wimmera bores							
Sands marls of upper beds at Beaumaris ? Middle part of Sorrento bore ?? Shell marls of coastal cliffs near Sherbrook River	Leaf beds overlying marine Barwonian at Sentinel Rock and (?) Pitfield Plains. Sands, clays, and ironstones with *Cinnamomum* at Bacchus Marsh		?? Alkaline intrusive rocks of Port Cygnet and Woodbridge	? Shell beds in well-sinkings at Tareena.	? Alkaline lavas and plugs of Canobias, Warrumbungle, and Nandewar Mountains. ? Plant beds of Warrumbungle Mountains with *Cinnamomum* in trachytic tuffs. Plant beds of Darling Plains, E. of Broken Hill Quartzite with *Cinnamomum* at Dalton, near Gunning		? Alkaline plugs of Glass House Mountains and lavas and tuffs of Main Range, Fassifern, Springsure, &c
Shell marls of Mornington, Muddy Creek (lower beds), Fyansford, Barwon Basin, Hollibrand, Mitchell River, and lower part of Sorrento bore. Limestone of upper beds at Mallee. Ironstones of Keilor and Royal Park (lower beds)		? Bryozoan limestone near Cape Grim and on Flinders and King Islands.					
Lepidocyclina and bryozoan limestones of Batesford, Keilor, Flinders, Muddy Creek bore, and East Gippsland bores	"Older Basalt" of Maude				? Eyre series of West Darling District.		? Eyre series of Central basin. ? Lacustrine beds of Rallie Creek, Duaringa, &c., and lignite of Waterpark Creek.
Shell marls and bryozoan limestones of Torquay. Limestone of Waurn Ponds and Maude (lower beds). ? Marls and limestones of Aire coast and clays of Cape Otway	? Deep leads with fossil fruits at Hoddle's Creek and Tanjil ?? Upper part of Yallourn series	"*Crassatella*" and *Turritella* beds of Table Cape	? Leaf beds of Macquarie Harbour.	Shell marl of South Ita bore. ? Ironstone of Arumpo bore			
Carbonaceous sands with *Cyclostoma* of Anglesea Cliffs. Torquay bore (110–840 feet), and near base of bores in East Gippsland, Mallee (Tiega bore), and Dartmoor	? Yallourn series, lignites, sands, and clays of Morwell and Yallourn Sands, sandy and ligneous clays beneath marine marls in Balcombe Bay bore, sands, clays, and lignite beneath Balcombian at Altona to Parwan (bores). Lignite and clays of Goon Nure bore, East Gippsland, sands and clays at base of Point Addis, Dartmoor, and Mallee bores Older Volcanic series (basalts, &c.) of Western Port, South Gippsland, &c Leaf-beds of Berwick, Narracan, Pascoe Vale, &c ? Deep leads of Stawell and upper Moorabool River		Basalt of Marrawah.		? Older Volcanic series (basalts) of New England. Vegetable Creek (Emmaville) leads with *Cinnamomum*.		Silkstone series of S.E. Queensland, shales, mudstones, and *Planorbis* limestone with associated basalt Redbank Plains series of S.E. Queensland with fish and plant remains near Oxley and Darra. Basalts of Redbank Plains and Cooper's Plains.

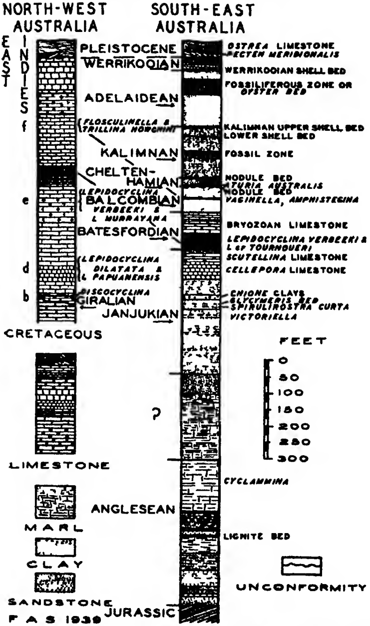


FIG 11 —Composite sections of the marine Tertiary rocks of North West and of South East Australia Broken lines link equivalent horizons in the two sections

Correlation with New Zealand.

Despite their geographic propinquity, the Tertiary faunas of Australia and New Zealand are notably distinct, at least specifically, and correlation between the two countries is difficult

At an early date Tate (447) recorded half a dozen species of brachiopods as common to the two countries, but later workers on the New Zealand faunas have accepted (450) only two Australian species. One of these, *Murravia catinuliformis* (Tate), occurs in the ***Liothyrella landonensis*** fauna, characterizing Allan's Duntroonian stage, regarded by Finlay as the lower member of the Upper Oligocene. The River Murray cliffs (Middle Murravian) constitute the type locality of this species (175), but it has been recorded (275, 543) from localities here referred to Janjukian, Balcombian, and Cheltenhamian stages, a wide range which induced Thomson (450, p 185) to suggest, probably rightly, that more than one species was included. Until this doubt is resolved the species cannot be utilized for correlation The other species, ***Stethothyris sufflata*** (Tate), with Port Vincent on Yorke Peninsula as type locality (543, p 253), is restricted in Australia to localities (275, 543) belonging to the horizon of Tate's Lower Aldinga series, here referred to the Janjukian In New Zealand, according to Thomson, it occurs only in the Weka Pass district, ranging from the calcareous mudstone following the main Mount Brown limestone (Hutchinsonian) up to the uppermost Mount Brown limestone (E) It may be noted that Marwick has placed the Hutchinsonian stage as Upper Oligocene, and more recently Finlay (321) as Lower Miocene, while the writer regards the Australian localities as Oligo-Miocene

The molluscan species supposed identical in the two countries have been listed by Finlay (485), but those critically examined by Marwick (501) proved in all but one case to be represented by allied rather than by conspecific forms, and the same applies to many other records, such as that of the Neozelanic "*Drillia*" *wanganuiensis* Hutton in the type Kalimnan fauna The exception is *Typhis maccoyi* T. Woods, with which Tate (538) regarded the Neozelanic ***Typhis hebetatus*** Hutton as synonymous, a conclusion concurred in by Marwick (501). The type locality of the former is Table Cape, Tasmania, to be correlated with the type Janjukian locality of Spring Creek, near Torquay, Victoria, where it is common in the lower sandy marls at the level of Bird Rock, but the species ranges into the Balcombian stage at Muddy Creek, Gellibrand River, and other Victorian localities, though it has not been recorded from Balcombe Bay

itself, as remarked by Pritchard (111, p. 48, footnote). In New Zealand it occurs in the Mount Harris beds which are referable to the Awamoan stage recently regarded by Finlay (321) as Middle Miocene, but previously by Marwick as Lower Miocene Thus, it is comparable in age to the range in Australia, in the writer's view from Lower Miocene or Oligo-Miocene to Middle Miocene.

While generic identities in the Mollusca are seldom of much value except for the broadest correlation, a notable exception is that of the Kalimnan *Heligmope dennanti* Tate (540, p 329) and the Waitotaran *Turbo postulatus* Bartrum, believed to be congeneric by Finlay (488), since his suggestion that *Heligmope* is Ianthinid and thus a pelagic genus is supported by examination of the protoconch of the Australian species In a second case, that of *Notovola*, this subgenus of *Pecten* had already reached New Zealand by Castlecliffian times, but not Australia until after the end of the Werrikooian, if the definition of this latter stage herein proposed be adopted.

The evidence of other groups is indecisive save perhaps for the Foraminifera Here the foraminiferal faunule described by Chapman from near Mount Oxford, South Island of New Zealand, contains *Discocyclina* and *Asterocyclina*, an assemblage recalling that from the Giralian stage in North West Australia, but having in addition *Assilina*, relegating it to stage *a* of the East Indian sequence, regarded as Middle Eocene Finlay (321) has referred the New Zealand occurrence to the Bortonian stage

The same author (321, 322) has suggested a correlation of the Australian Janjukian with the Waitemata beds (Hutchinsonian) based on his identification from Torquay, the type Janjukian locality, of *Calcarina mackayi* (Karrer), a species restricted in New Zealand to the Waitemata beds (Hutchinsonian) Finlay also records it from Whakau stream, Poverty Bay, with abundant *Nephrolepidina* and *Miogypsina*. This orbitoid-bearing horizon, is rather to be correlated with the Australian Batesfordian as herein defined, than with the Janjukian as supposed by Finlay, doubtless owing to Chapman's reference, from which the writer dissents, of the Batesford limestones to the Janjukian

Attention may also be drawn to *Miogypsinoides dehaarti nitidula* Chapman, which has been recorded by that author (65) from Quobba Cliffs, North West Australia (fig. 1) and also from limestones in the Mount Somers district, New Zealand, which are referred to the Hutchinsonian (Speight, 1938, *N.Z. Geol. Mem.* 3).

A tentative, and probably premature, correlation of the Australian Tertiary stages with those of New Zealand, as set out by Finlay (321), is as follows:—

		New Zealand (Finlay, 1939)		Australia (Singleton, 1939)	
Pliocene	U	Castlecliffian		Werrikooian (? new stage)	
	M	Nukumaruan		Adelaidean	
	L	Waitotaran Opoitian		Kalimnan	
Miocene	U	Taranakian		Cheltenhamian	
	M	Awamoan		Balcombian	Barwonian
				Batesfordian	
	L	Hutchinsonian		Janjukian	
Oligocene	U	Waitakian		(? new stage) Anglesean	
		Duntroonian			
	M	Whaingaroan	Ototaran		
	L	Kaiatan		(? new stages)	
Eocene	U	Tahuian	Waimatean	Geralian	
	M	Bortonian			
	L				

[Addendum. Allan (443) in a paper bearing the date 9th April, 1940, has described as a new species *Stethothyris epsilon*, the New Zealand brachiopod hitherto identified as the Australian *S. sufflata* (Tate), which latter is transferred to a new genus *Victorithyris*, the two species being homoeomorphs. He has also identified from the Upper Janjukian limestone of "Rocky Point, mouth of Spring Creek, Torquay, Victoria" (443, p. 285) the Neozelanic *Neobouchardia minima* (Thomson), originally described from the main Mount Brown limestone (Hutchinsonian), but ranging downward to the Duntroonian. It may be noted that Allan's "Rocky Point" is local usage for the point immediately south of the mouth of Spring Creek, shown on the military map and in fig. 7 as Jan Juc and to be identified with Pritchard's "Scutellina Limestones" (155). In 1936 Allan did not visit the true Rocky Point (locally also known as Pride's Leap) of fig. 7, the military map and the usage of Tate and Dennant (183, p. 209) and of Hall and Pritchard (107, p. 156). F. A. S., 29.4.40.]

Discussion of Sequence

In Section III., the writer has attempted to summarize the views of other writers and in Section IV. his own views on the vexed problems of the sequence and correlation of the Australian

marine Tertiary deposits There remains the necessity to indicate the evidence on which these latter views are based and wherein they may be opposed to those of other workers: such evidence can be here presented only in outline

The Relation between Anglesean and Janjukian.

In 1910, Hall (102) noted that the black sandstone or sandy clays of the cliffs north-east of the Anglesea River seemed to show a gentle anticline, but attributed it to the effect of weathering following the contour of the ground He concluded that these black sandy beds were apparently the equivalents of the rich marine beds of Spring Creek, or in other words that the Anglesean and Janjukian were different marine facies of approximately the same age

Nevertheless, the writer believes the anticlinal structure (see Pl I fig 1) to be real, and evidenced on the westerly limb by the dip of the junction between the black sandstone and overlying white sands (*supra*, p 25), although the fold axis may not trend in the direction shown by Coulson (686, fig 1). To the east between the Black Rocks and Point Addis there is a gap in the coastal section, occupied by sand dunes which thus mask the relation between the Anglesean black sandy beds and the probably Janjukian limestones of Point Addis, though it must be admitted that the latter dip towards instead of away from the Demon's Bluff section Since, however, gentle folding of the Tertiary strata between Torquay and Anglesea is present, this dip, which is also shown by the erosion surface (44) within the limestones on the west side of Point Addis, probably lacks stratigraphical significance Of more importance is the evidence of the borings for oil made by the Point Addis Company at Point Addis (37, p. 21), but, although the bore logs are available (38, pp. 17, 18), this is not the case with the cores themselves, which remain undescribed, so that their interpretation remains doubtful. The same applies in a measure to the bores (37; 38, pp. 15-17) put down by the Torquay Oil Wells Company near the Janjukian type locality south-west of Torquay (Fig. 8), though the general sequence has been stated by Chapman and Singleton (27, p 996, and *supra*, p 39) and the bore logs (38) have been utilized in the preparation of the composite section in fig 11, which suggests a possible intervening stage In the deeper portions of these bores in the Parish of Jan Juc the richly fossiliferous Janjukian beds are underlain by strata probably referable to the Anglesean, which in some cases contain *Cyclammina* and are often lignitiferous towards the base

This sequence of these stages is supported by the evidence of borings in the Mallee, Dartmoor and East Gippsland districts in the north-west, south-west, and south-east of Victoria respectively.

The Relation between Janjukian and Balcombian

This, the most controversial topic in Australian Tertiary stratigraphy, requires separate treatment, even though the writer believes it desirable to recognize the Batesfordian as an intermediate stage. It will be apparent from Section III. that Tate and Dennant, though reversing Hall and Pritchard's sequence, here adopted, of the above stages, nevertheless placed the Lower Aldinga beds, here correlated with the Janjukian, at the base of their sequence and hence in an infra-Balcombian position. Although Chapman, the other principal protagonist of the post-Balcombian age of the Janjukian, appears recently to have greatly modified this view (*supra*, p. 11), it is necessary to examine the arguments he has advanced in support of it (23).

Hall and Pritchard relied largely, as does the writer, on the sequence displayed in the valley of the Moorabool River between Maude and Fyansford (map 2; figs. 5 and 12). Their view is based chiefly on the correlation of the lower Maude limestones with the Janjukian and of the Upper Maude limestones, separated from them by the intervening Older Basalt, with the Balcombian, though the local nomenclature had not been instituted at the time of their paper (106). While the lower Maude mollusca include several species apparently restricted to the locality, many of the most characteristic, such as *Eotrigonia intersitans* (Tate) and *Eucrassatella maudensis* (Pritchard), also occur at Torquay, and the correlation with the Janjukian, though unacceptable to Tate and Dennant (185, p. 138) appears justified. The reference of the upper Maude beds to the Balcombian is less well established, though the writer believes them to represent a littoral facies of the Fyansford clays, whose Balcombian age is discussed below. Although detailed mapping of the lower Moorabool valley is desirable, Hall and Pritchard (104, 106, 109) have already shown that the generally downstream dip of the Tertiary rocks results in the disappearance below river level first of the lower Maude beds, followed by that of the Older Basalt, about half way between Bannockburn and the Sutherland's Creek Junction. Downstream from this locality the southerly equivalent of the upper Maude beds is represented by the Batesford bryozoan and lepidocycline limestones (Batesfordian) and the Fyansford clays (Balcombian), which overlie them in turn above Griffin's (fig. 5).

Since the reference of the lower Maude beds to the Janjukian and the general stratigraphical sequence have not been challenged by Chapman, it is evident that the crucial point lies in the age of the clays at Orphanage Hill, Fyansford, which nearly all workers, including McCoy, correlated with those of Balcombe Bay. In 1911 Chapman (455, p. 421) had himself referred the Orphanage Hill locality to the Balcombian, but three years later (23, p. 39) thought its affinities were rather with the Janjukian,

FIG. 12.—Geological map and section of Maude district, Victoria. Geology from Quarter sheet No. 19 S.W., Geological Survey of Victoria, 1865, with emendations and additions. Contours from Meredith sheet, Military Survey of Australia, 1936.

on the evidence of five of the species recorded by Hall and Pritchard (104), asserted by Chapman to be restricted Janjukian fossils.

The first, *Terebratula vitreoides* T. Woods, although later listed by Crespin and Chapman (450) from Fyansford as a new record, probably refers rather to *T. tateana* T. Woods (cf. 543, p. 251), which is a *Liothyrella* apparently ranging throughout the Barwonian. The next two, *Natica gibbosa* Hutton and *Pleurotoma haasti* Hutton, are almost certainly wrongly identified with those Neozelanic species. In any case the former has not been recorded from the type Janjukian locality or any other whose correlation with it is undisputed, while the latter was deleted by Hall from his own reference copy of Hall and Pritchard's paper (104) and has been omitted from Dennant and Kitson's catalogue (275). Nor do the last two names cited by Chapman, *Limopsis insolita* (Sowerby) and *Cardita gracilicostata* T. Woods, fare any better. The former was not, in fact, listed by Hall and Pritchard, and has since been shown by the writer (525) to differ from Sowerby's species and has been named *Limopsis chapmani* Singleton, a characteristic Janjukian species. But the Fyansford shells prove to be not "*insolita*" (i.e., *chapmani*) but slightly decorticated examples of *L. morningtonensis* Pritchard, which is a species characteristic not of the Janjukian but of the Balcombian.

An Orphanage Hill shell identified by T. S. Hall as *Cardita gracilicostata* T. Woods, is very much smaller than and almost certainly not conspecific with topotypes from Table Cape of *Venericardia gracilicostata* (T. Woods).

Thus it is seen that none of the five species listed can be claimed as a restricted Janjukian fossil and actually none, save for the erroneously identified *Limopsis* "*insolita*," is recorded from the type locality of the Janjukian by Dennant and Kitson (275). This is significant in that Chapman appears to have regarded as a restricted Janjukian fossil one which is present in beds which he correlates with the Janjukian, such as those in the Barwon-Lower Moorabool basin (referred by Hall and Pritchard to the Balcombian), whether or not it occurs at Spring Creek, Torquay, the type locality of the Janjukian (cf. 57, p. 385, of the Mallee bores fauna. "*Gypsina howchini*, Chapm. A restricted Janjukian fossil, known previously only from Batesford.") This is clearly inadmissable, and species supposed restricted to a stage should either occur at the type locality of that stage or at least only at localities whose correlation with the type locality is undisputed.

On the above criteria a much longer list can be made of restricted or characteristic Balcombian molluscan species in the Fyansford fauna, including *Limopsis morningtonensis* Pritchard, *Eucrassatella dennanti* (Tate), *Cerithium apheles* T. Woods,

Umbilia eximia maccoyi Schilder, *Gigantocypraea gigas* (McCoy), *Austrotriton textilis* (Tate), *Chicoreus lophoessus* (Tate), *Dennantia ino* (T. Woods), *Pterospira hannafordi* (McCoy), *Volutospina antiscalaris* (McCoy), *Conus ligatus* Tate, *Vaginella eligmostoma* Tate.

The Fyansford fauna, then, like that of Murgheboluc, Inverleigh, and other localities in the Barwon River basin, is in actual fact Balcombian and not, as claimed by Chapman, an argillaceous facies of the Janjukian, with a supposed persistence of Balcombian species owing to uniformity of conditions. Argillaceous horizons are well developed in the type Janjukian section, but contain faunas with marked differences from those of Fyansford and Balcombe Bay.

Hamilton District.—In a valuable account of this area Chapman (23) referred the lepidocycline and polyzoal limestone of the Grange Burn, like that of Batesford with which he justifiably correlated it, to the Janjukian, and placed it between the Balcombian of Clifton Bank and the Kalimnan of MacDonald's and Forsyth's. But the Batesfordian limestones at the junction of Muddy Creek and Grange Burn rest directly, as reported by Dennant (83), upon the surface of Palaeozoic quartz porphyry, so that if the Balcombian marls were in an inferior position their absence here could only be attributed to overlap by the limestones. The Hamilton bore (Parish of Yulecart, No. 1) on Muddy Creek, which started on the horizon of Clifton Bank and about 50 chains downstream, penetrated lepidocycline limestones (311, p. 5) which incontestably are the older. The Lepidocyclinae, since the record of *Spiroclypeus* (305) has been shown (311, p. 11) to be erroneous, indicate a Batesford horizon, and true Janjukian strata do not outcrop in the Hamilton area.

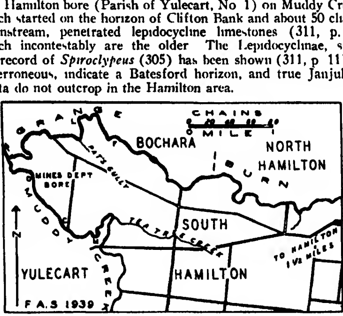


FIG. 13.—Map of Muddy Creek district, near Hamilton, Western Victoria. C. Clifton Bank (Balcombian), F. Forsyth's Bank (Kalimnan), M. MacDonald's Bank (Kalimnan), L. Lepidocycline limestone (Batesfordian).

Sorrento Bore.—While Chapman (63) has correctly referred to the Balcombian the lower horizons of this bore, down to its base at 1,696 feet, his reference of the overlying strata between 758 and 1,295 feet to the Janjukian is based on very inadequate evidence. He ascribed the absence of Lepidocyclinae in the bore to deeper water conditions, but it seems more probable that if the bore were deepened the Batesfordian lepidocycline beds would be penetrated, and possibly also the Janjukian.

Aire Coast (50, 110).—The basal beds at Wilkinson's No. 5 locality or Castle Cove (fig. 14), which dip at about 40° south-easterly off the Jurassic bedrock, consist chiefly of hard ragged limestones whose fauna recalls that of the Lower Aldinga beds in South Australia. Overlying them are grey marly limestones with *Limopsis chapmani* Singleton, a characteristic species of the lower Janjukian at the type locality and also at Aldinga. At Wilkinson's No. 1 locality, Point Flinders, near Cape Otway, black clays contain a rich molluscan fauna (184), referable to the Janjukian, in which the Lower Aldinga facies is prominent.

At Wilkinson's No. 4 locality a Janjukian shelly fauna occurs in grey sandy clays interbedded in a series of clays and bryozoan limestones also dipping south-easterly but at about 20°. At Wilkinson's No. 3 locality, between Nos. 4 and 5, but separated from them by Pleistocene dune limestones, bryozoan limestones, apparently also referable to the Janjukian, dip north-westerly at a little more than 10°.

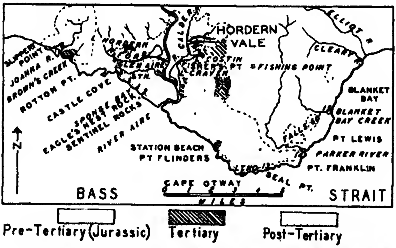


FIG. 14.—*Geological map of Aire District, near Cape Otway, Victoria.* Modified from maps by Wilkinson, 1865 (50), Krausé, 1874 (34), and Hall and Pritchard, 1899 (110). C.L., Calder limestones. LT., Lighthouse. S.P., Spud Point. Figures refer to localities numbered by Wilkinson.

About a mile inland from these coastal sections (fig. 14), and separated from them by Pleistocene dune limestones and Recent sand dunes, practically horizontal clays and soft bryozoan limestones outcrop on the left bank of the Calder River from Fisher's Point (or Fischer's Point; Fishing Point of Hall and Pritchard (110) and of Dennant and Kitson (275)) southward The molluscan fauna (110) of Fisher's Point is clearly Balcombian, though the abundance of *Amphistegina* near the top of the section suggests a horizon similar to that of Clifton Bank, Muddy Creek, where this genus is abundant, and probably slightly older than that of Balcombe Bay, where it is wanting

Though there is as yet no stratigraphic proof of sequence, it is suggestive, as pointed out by Hall and Pritchard (110, p 54) that the Janjukian strata of the coastal sections show relatively high dips, due apparently to folding, whereas the Balcombian strata, a short distance inland, remain sensibly horizontal This may indicate an unconformity between Janjukian and Balcombian beds, for Batesfordian rocks are unknown in this area, though probably the Anglesean stage is represented by the dark clays with *Cyclammina* of Brown's Creek (26, 297)

Mallee Bores.—Though Chapman (23, p 49; 57, p 380) has claimed the borings in the Victorian Mallee show a gradual passage from Janjukian to Kalimnan, it is probable the pre-Kalimnan beds are instead largely Balcombian, since the important restricted foraminiferal species *Trillina howchini* Schlumberger, first described from Clifton Bank, is recorded from several of these bores (57, pp. 335, 338, 339, 360) and others in the Mallee (311, p 6)

The Relation between Janjukian and Batesfordian

No exposed section is as yet known where this may be demonstrated and reliance must be placed on the relation above discussed between Janjukian and Balcombian, together with the conformable relations dealt with hereunder between Batesfordian and Balcombian

It is possible, however, that the missing evidence may be supplied by the stratigraphy of the East Gippsland basin (fig 15), of which numerous bore cores are being investigated. In this area the Batesfordian stage is represented by marly bryozoan limestones with *Lepidocyclina*, which comprise zones B2 and B3 of Chapman and Crespin (25). These authors record them, as Lower Miocene, in the Metung bore (Parish of Bumberrah, No. 1) between 700 and 873 feet, in the Jemmy's Point bore (Parish of Colquhoun, No. 1, or Lakes Entrance, No. 3) between 770 and 840 feet, and in the Rigby Island bore from 685 to 890 feet. This latter, which is Chapman and Crespin's Kalimna bore (26, pp 118-120) is also known as Lakes Entrance, No. 4, or Kalimna, No. 1. On a lower horizon is their A2 zone, regarded by them as Upper Oligocene and

represented by micaceous foraminiferal marls underlain by glauconitic sandstone. From the micaceous series Chapman and Crespin (25, pp. 6, 7, 26, p. 119) record as restricted foraminifera *Cyclammina incisa* (Stache), *Vaginulina gippslandica* Chapman and Crespin, *Lamarckina glencoensis* Ch. and Cr., and *Victoriella plecte* (Chapman). The last named (267, p. 320, 303) is a restricted species of the lower Janjukian of the type locality, below the summit of Bird Rock, where it is also associated with *Cyclammina*. The micaceous series, occurring in the above mentioned bores at 1,115–1,370, 1,100–1,331, and 1,160–1,385 feet respectively, may therefore be referred tentatively to the Janjukian stage, as may also the underlying glauconitic bed, at 1,396–1,432, 1,331–1,396, and 1,387–1,410 feet respectively, since the writer has provisionally determined therefrom *Turritella (Colpospira) aldingae* Tate. It may be noted that discrepancies between the above figures and those given by Chapman and Crespin (25, p. 13) are due to supersession of the latter by those of the Boring Records 1923-30 (38, pp. 24 and 89).

The Relation between Batesfordian and Balcombian

Since these are represented at their respective type localities by strata of contrasted lithology, it might be questioned whether the faunal differences between them may not be due only to differences in facies.

Nevertheless, a conformable succession of Batesfordian by Balcombian strata is demonstrable along the Lower Moorabool River between Batesford and Fyansford (*supra*, pp. 31, 70, and fig. 5) while their superposition was shown beyond doubt by the sections exposed during construction of the tunnel to the new quarry of Australian Cement Ltd. near Batesford.

The Hamilton bore (Parish of Yulecart, No. 1; 38, p. 88) on Muddy Creek (fig. 13), which started near and just below the level of the Balcombian of Clifton Bank, penetrated Batesfordian strata with abundant Lepidocyclinae from 10 feet down to 230 feet (305, 311, p. 5).

At Keilor (77, 108) fossiliferous ironstones, which the writer agrees with Hall and Pritchard in regarding as a littoral facies (108, 155) of the Balcombian, overlie a small exposure of Batesfordian lepidocycline limestone.

At Maude the upper limestones are divisible, as first noted by Tate and Dennant (185, p. 138), into a hard limestone with littoral shells, probably a facies of the Balcombian, and an underlying softer bryozoan limestone. This latter resembles in lithology and fossils part of the Batesford limestones, though *Lepidocyclina* is not yet known to occur.

Since in the first three of the above areas a Batesfordian lepidocycline limestone is succeeded by fossiliferous beds which

are definitely or tentatively referable to the Balcombian, there is strong presumptive evidence for the view that these are distinct but consecutive stages, rather than contemporaneous facies.

Only at Skinner's (91), on the Mitchell River near Bairnsdale, are Lepidocyclinae (311) associated with *Trillina howchini* and with a molluscan fauna of Balcombian affinities. Whether this represents an argillaceous facies of the Batesfordian with its shelly fauna is not yet clear

The Relation between Balcombian and Cheltenhamian

This is demonstrated at Beaumaris, the Cheltenhamian type locality (*supra*, p 32), where the stratigraphic break occurs at the base of a "nodule bed" The underlying Balcombian strata are marls with concretionary limestones which give rise to white pebbles in the shingle. They thus resemble lithologically the beds of Balcombe Bay and Grice's Creek, and are not littoral deposits as stated by Chapman and Crespin (26, p 122)

At Balcombe Bay (*supra*, p 27) and at a small gully immediately south of Manyung Rocks, on the coast about a third of a mile south of Grice's Creek, a series of ferruginous sands and grits rests with an even junction upon the fossiliferous Balcombian marls This ferruginous series is apparently barren at these localities, but at Landslip Point (23, 111) near Frankston, a band containing fossil moulds and casts occurs apparently in the same series Chapman (23, p 29, 59) has sought to show that they are referable to the Janjukian, but two of the forms on which he relied are not definitely identified, being listed by him as *Terebratula* (?) *aldingae* Tate and *Pecten* cf *flindersi* Tate

Though the type locality of the third, *Pecten praecursor* Chapman, said to be "a specially characteristic Janjukian form" is Spring Creek, Torquay, Chapman cites records from localities such as Shelford, Lower Moorabool and Curlewis-Belmont, whose reference to the Balcombian by Hall and Pritchard (112) is supported by the writer There is thus little to set against the close resemblance of the rest of the fauna (111) to the Balcombian, and these ferruginous beds, at least in their older part, constitute an immediately post-Balcombian series which may represent wholly or in part the disconformity between Balcombian and Cheltenhamian at Beaumaris

The Relations of the Cheltenhamian.

The molluscan fauna at the type locality shows an association in a single stratum, about 2 feet above the nodule bed, of Kalimnan species with a subordinate but well-marked Barwonian element Similarity of preservation precludes a remanié origin for the latter, which, indeed, had induced Tate (181) to correlate these beds with those of Spring Creek the type locality

of the Janjukian stage That the Cheltenhamian is post-Balcombian is shown by superposition at Beaumaris (*supra*, p. 32), that it is post-Batesfordian by the discovery by W. J. Parr (personal communication) in the nodule bed and immediately overlying strata of worn and glauconite-filled remanié Lepidocyclinae

While direct superposition of Kalimnan upon Cheltenhamian strata is not definitely demonstrable, the inferior position of the Cheltenhamian is established on palaeontological grounds It is even possible that the upper ferruginous sandstone (*c*) of the Beaumaris cliff sections (*supra*, p. 33) may ultimately prove to be Kalimnan and the overlying white sands (*d*), like similar beds throughout the south-eastern suburbs of Melbourne, are probably younger still, perhaps Middle or Upper Pliocene or even, as above suggested, Pleistocene.

The Relations of the Kalimnan.

At the type locality, Jemmy's Point, Kalimna, deep borings show the Kalimnan strata to rest apparently conformably, or at all events without a basal nodule bed, upon a thick calcareo-argillaceous series which in its upper part is presumably of late Barwonian age. Similar relations obtain in many other borings in East Gippsland and also in the Mallee At Royal Park (108, 158) near Melbourne ferruginous (hematitic) beds, here regarded as Balcombian, are overlain by limonitic beds with a scant fauna which may be Kalimnan There is no visible unconformity, but a concealed disconformity may be present

Elsewhere, as at Muddy Creek and Grange Burn, near Hamilton, the typically Kalimnan beds of MacDonald's and Forsyth's are separated from the underlying Balcombian by a thin nodule bed marking a stratigraphic break The relation of the Kalimnan to succeeding beds is obscure, but it may be noted that many of the beds referred to the Kalimnan in the Melbourne district may equally well be post-Kalimnan

The Relations of the Adelaidean

Since beds of this stage are known definitely only from borings, stratigraphical evidence is limited Nevertheless, the shelly fauna of the Adelaidean shows a marked Kalimnan relationship, so that the two were correlated by Mrs Ludbrook (140) and some earlier authors (27, 112) The Adelaidean fauna contains, however, at least twice the percentage of living species and it is probably post-Kalimnan (44, 126, 177, 275), a position perhaps supported by the evidence of the Abattoirs bore (fig 3).

On the other hand, there is sufficient difference between the Adelaidean and Werrikooian faunas to suggest a possible intervening stage yet to be recognized, and Howchin's equation (5) of the two stages cannot be justified

The Relation between Werrikooian and Pleistocene

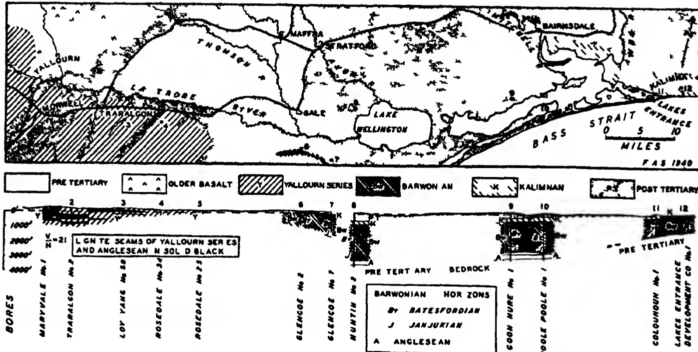
Whether the Werrikooian should be included in the Tertiary or in the Pleistocene has long been the subject of debate. Originally these beds were regarded by Dennant (82, 84) as Pleistocene; then by Tate and Dennant (183) as Newer Pliocene, by Tate (144, p. 84) as Older Pleistocene, by Hall and Pritchard (112) as Pliocene; and by Dennant and Kitson (275), Chapman (22, 23), Chapman and Singleton (27), Chapman and Crespin (26), and the writer (17, 44) as Upper Pliocene. The changes of view by Tate and by Dennant were due to varying opinions as to whether or not most of the extinct molluscan species were of extraneous origin The writer (43, p 983) has shown that many of these are in actual fact derived from outcrops of Barwonian clays along the Glenelg River, washed out specimens from both horizons having been indiscriminately collected, and therefore suggested that the Werrikooian might have to be removed to the Pleistocene as advocated by Tate. Nevertheless, a critical study has shown that about 5 per cent of the mollusca are extinct species, so that the Werrikooian may be placed as Uppermost Pliocene (159), immediately preceding the Pleistocene with a molluscan fauna of living species only

The stratigraphic succession supports this view (*supra*, p. 47), but if the Pleistocene be marked by *Pecten* (*Notovola*) *meridionalis* Tate, then the Dartmoor oyster bed (*supra*, p. 48) must be referred to the Pleistocene rather than to the Werrikooian as done by Chapman and Crespin (26, p 124)

The Relations of the Yallourn Series.

Since at the type locality marine Tertiary formations are absent, the difficulty arises that where relations between marine and non-marine strata obtain, the correlation of the latter with the Yallourn series may be unjustified Indeed, this objection has been raised by Sussmilch (18, p xv) to the writer's correlation (17) of the Yallourn lignites with the much thinner lignites underlying marine strata further to the east (*supra*, p. 50). It must be conceded that the attenuated non-marine strata beneath the marine Barwonian of the western part of the East Gippsland Tertiary basin are not equivalent to the whole thickness of the Yallourn series. Thus far Sussmilch's criticisms may be accepted, but not his claim that the upper part of the Yallourn lignites, with plant remains, might be as young as Lower Pliocene.

The thickness of the Yallourn series at Morwell was asserted by Sussmilch (18) to be comparable with that of the marine strata of East Gippsland, but the latter reaches 2,588 feet at the Lake Kakydra bore (Parish of Nuntin, No. 2) near Sale (41, pp. 30, 35), which also passed through 455 feet of lignite seams and non-marine sediments interbedded with marine horizons



F G 1a —Geolog cal map of part of East G ppsland V cto a an1 ec on n he La obe Va ley bo es 1 7) from Mo we l to 4 m les E of Longford and n the G ppsland Lakes area bo es 8 2) f om Lake Kakyd a o l ake Bung Mod fied from Geolog cal Survey of V ctor a maps and bor ng reco ds (36 38 39 40 41 624

(Anglesean?) before reaching bedrock at 3,480 feet. In any case the rate of accumulation of lignites is probably greater than that of the marine sediments, and even the upper part of the Yallourn series is unlikely to be younger than the lowest part of the Barwonian (*supra*, pp 50, 57), while the main portion is probably approximately equivalent to the Anglesean

The general relations in the East Gippsland Tertiary basin are shown by two sections in fig. 15. The bores in the Parish of Glencoe did not reach bedrock, but showed equivalent Tertiary horizons at a much higher level than in the Lake Kakydra bore (Nuntin No 2) which is probably near the deepest part of the Tertiary basin This difference of level may well be accounted for by the strong northerly dip shown by Parish of Glencoe borings Nos 1–5 and by outcrops at Le Grand's Quarry, Longford, in the same Parish

The lignitic series to the north-west of Port Phillip from Altona to Parwan underlies Balcombian fossiliferous marls and is thus pre-Middle Miocene, but the lower limit of age is uncertain At Altona an early boring is said to have encountered shells in "fine white quartz-drift" below the brown coal (108, p 218; 648, p. 82)

Borings (38, pp. 42, 57) south-west of Parwan (Parish of Mouyong, Nos 2 and 6) have penetrated a 6-ft. lignite seam with fossiliferous marine strata above and below · unfortunately, these faunas have not yet been studied Beneath in No 2 bore is a thicker lignite probably correlable with that of Altona

Small seams of lignite occur, as above noted, beneath the marine beds of the East Gippsland basin south of Sale and of Bairnsdale, in the Tyabb bores (36, p 28), and a 15-ft. seam beneath the type Janjukian in Torquay bore No. 4 (38, p.17).

In South Australia the Moorlands lignite (613, 640) also underlies marine Barwonian The only lignites that come into direct relation with probable Lower Pliocene marine rocks are near Gelliondale in South Gippsland, where they underlie a marine fauna referred by Chapman and Crespin (26, p. 120) to the Kalimnan. Thus they are pre-Kalimnan, but how much older is uncertain

Though all these occurrences of lignites are not necessarily on the same horizon, in general they agree in being antecedent in the main to the principal or Barwonian marine deposits, and it is therefore not unreasonable to refer the bulk of the lignitic series to the Oligocene

The Relations of the Older Volcanic Series

Where the Older Volcanic series or Older Basalts come into relation with Tertiary marine rocks, they are usually unconformably overlain by Janjukian, Batesfordian or Balcombian

deposits (*supra*, p. 53), except at Maude, where the older volcanic rocks occur between the lower and the upper Maude beds.

Airey's Inlet.—At Eagle Rock and Split Point near Airey's Inlet (102, p. 49), the eroded surface of basalt flows and tuffs of the Older Volcanic series is overlain by bryozoan limestones which have been correlated (102) with the limestones of the Upper Janjukian of the type section. It is, however, possible that the horizon may ultimately prove to be lower in the Janjukian stage. It may be noted that none of the deep borings at the type locality (38, pp. 15–17) encountered basalt.

Flinders.—Bryozoan limestone with *Lepidocyclina* and calci-sponges rests on the eroded surface of "Older Basalt," which is here of great thickness, though locally there intervenes a thin conglomerate of basaltic pebbles. The section given by Chapman (23, p. 33) is in error in showing the limestone as Janjukian and the overlying material as decomposed Newer Basalt. The former is Batesfordian and the latter, as correctly shown in Kitson's section (137), is clay washed down from weathered Older Basalt at a higher level. Newer Basalt is unknown on Mornington Peninsula.

Keilor.—At Green Gully near Keilor, a small exposure of Batesfordian limestone (77) rests directly on Older Basalt and is itself overlain by ironstones with a shelly fauna probably of Balcombian age (17, 108).

Royal Park.—In the railway cutting south-west of Royal Park station (108, 158), the eroded surface of Older Basalt is overlain by ferruginous sandstones and ironstones with a fauna similar to that of Keilor and like it referred by Hall and Pritchard and the writer to the Balcombian, but by Chapman to the Janjukian.

Mornington District.—At Grice's Creek, Hall and Pritchard (111, pp. 39, 44) described the Balcombian clays as dipping at a high angle towards the basalt and then at a still higher angle off it, and regarded the igneous rock as the older. The writer agrees with this sequence, but believes the dip of the clays, as shown by the intercalated concretionary limestones, to be uniformly away from the basalt in a downstream direction; the junction is obscure and may be due to faulting.

Chapman, however, gave a generalized section (23, p. 30) showing the basalt as intercalated between the Balcombian clays and an overlying ferruginous series referred by him to the Janjukian (59), a correlation above criticized (p. 77).

At Balcombe Bay the Older Basalt is exposed at the first point south of the Cement Works, but its relation to the Balcombian clays north of the Cement Works is obscure, and

little light is thrown on it by Hall and Pritchard's (111) and Chapman's (23, p. 26) sections The writer believes a fault with northerly downthrow intervenes between this point and the cement works Decisive evidence as to the position of the basalt beneath the Balcombian at its type locality has since been furnished by Parish of Mooroodue bore No 6 (36, p 30, and *supra*, p 27)

Curlewis—Here also, as first shown by Hall and Pritchard (105) and recently confirmed by Coulson (76), the Older Volcanic tuffs and basalt are antecedent to the Tertiary clays and bryozoan limestone, and not younger than them as originally supposed by Daintree (79), whose sketch section has been reproduced by Chapman (260, p 215) The last-named author (23) agreed with Daintree in placing the main volcanic series above the limestone, but regarded the underlying blue clay as itself resting on an ash bed, the clay and limestone being referred to the Janjukian The fauna of the clays is, however, Balcombian, and the whole of the volcanic rocks pre-Balcombian

Maude—The occurrence of a considerable thickness of basalt between marine Tertiary beds in the valley of the Moorabool River near Maude (*supra*, p 70, and fig 12) has been admitted by all observers There is, however, disagreement as to the age of the overlying marine strata, the Upper Maude beds having been referred by Hall and Pritchard (112) to the Balcombian and by Chapman (23) to the Janjukian, and as to whether there is a second flow of basalt intercalated in the lower part of the Upper Maude beds

On Quarter-sheet No 19 S W of the Geological Survey of Victoria, 1865, mapped by C. S. Wilkinson and R A F Murray, a thin limestone is shown within the upper part of the Older Volcanic series, but Hall and Pritchard (106) were unable to find any evidence of it in the field. Chapman (23, p. 42), however, claimed this could be seen below Maude township on the Knight's Bridge road After examination of this section and others in the district, the writer unhesitatingly supports Hall and Pritchard's view At the spot cited by Chapman and immediately north of the outcrop on the Knight's Bridge road of the hard bryozoan limestone of the Upper Maude beds, there are two small excavations In the upper quarry 2 ft 6 in of cross-bedded bryozoan limestone rest on 1 foot of hard bryozoan limestone, and this upon very decomposed basalt Between this exposure and the road the lower quarry shows basalt, vesicular at the base, at a lower level. In neither case is the lower limit of the basalt visible, and Chapman's belief in an intercalated basalt flow 18 inches in thickness may be due to his having produced laterally two basalt-limestone contacts at different

levels. The alternative view of the writer is that the eroded surface of the basalt, on which the limestone rests, is a very uneven one.

Other traverses on the left bank of the Moorabool River also fail to show any trace of a later flow of Older Basalt, enclosed within the Upper Maude beds. In some of these traverses the marine Tertiary beds are underlain by varying thicknesses, from a few feet upwards, of non-marine sandstones or pebble beds (16, 23, pp. 40, 41). These appear to be absent in the second gully north of the Knight's Bridge road, where the sequence, with approximate thicknesses, is from above—

Upper Maude beds (52 feet)
 Sandy marls with calcareous concretions and a ferruginous grit band about 10 feet from top (36 feet?).
 Hard limestone, bryozoan in lower 2 feet (15 feet?)
 Basaltic pebble bed (1 foot)
Older Basalt (80 feet)
Lower Maude beds (65 feet).
 Sandy rubbly limestone (20 feet?)
 Fine bedded sandy limestone (8 feet?)
 Massive sandy limestone (12 feet)
 Fine sandy marls, with some discontinuous pebble bands (25 feet)
Ordovician slates and sandstones

Succeeding the Upper Maude beds immediately to the north of Maude township is Newer Basalt of about 50 feet thickness, overlying marls and a hard sandstone, which are possibly to be separated from the Upper Maude beds and to be referred to the Pliocene.

The Older Volcanic rocks of Maude are thus, in the view of Hall and Pritchard and of the writer, post-Janjukian and pre-Balcombian, those of Airey's Inlet are at latest pre-Upper Janjukian. Whether those of Curlewis and Mornington, which are overlain by Balcombian marls, are to be correlated with those of Maude or with those of Airey's Inlet, as is here done, remains uncertain.

Summary.

Marine Tertiary formations form a discontinuous fringe along 5,000 miles of the west and south coasts from North-West Cape in Western Australia to near Lakes Entrance in Victoria, and in N.W. Tasmania. Differing views as to their classification in S.E. Australia have been expressed by McCoy and the Victorian Geological Survey, by Tate and Dennant, by Hall and Pritchard, and by Chapman and his associates.

To the Upper Eocene are referred *Discocyclina* limestones in the Giralia Range at the head of Exmouth Gulf, and elsewhere in N.W. Australia; and perhaps also shales with a faunule of smaller foraminifera from deep borings near Perth, in S.W. Australia. Probably Upper Oligocene are *Eulepidina* limestones

in the N.W. Cape Range and the earliest marine strata of S.E. Australia Chiefly Lower to Middle Miocene is the main development of marine Tertiary strata, including *Nephrolepidina* limestones as well as richly fossiliferous clastic sediments, and several stages may be recognized in Victoria, where Upper Miocene may also be present. Marine Pliocene beds, in at least three stages, occur in S E Australia.

The marine stages, which are formally defined and whose stratigraphical relations are discussed, are from older to younger, Giralian, Anglesean, Janjukian, Batesfordian, Balcombian, Cheltenhamian, Kalimnan, Adelaidean, Werrikooian, with probable new stages to be interpolated before and after the Anglesean and between Adelaidean and Werrikooian

Correlation with adjacent countries is not far advanced, but foraminiferal faunules indicate that stages *b*, *d*, *e*, *f* of the Netherlands East Indies are represented in Australia Only approximate correlation with stages in New Zealand is as yet possible.

Non-marine deposits occupy wide areas, especially in the interior, but are difficult to date except in the south-east, where they come into relation with marine deposits. Important lignites, chiefly Oligocene, are developed notably in Victoria Other deposits, mainly fluviatile or lacustrine, may be tentatively referred to various horizons from Eocene to Pliocene, but can seldom be satisfactorily correlated, since the terrestrial vertebrate fauna is almost unrepresented prior to late Pliocene times

Igneous rocks, largely basaltic, but including alkaline and acid lavas and intrusions, are well developed on horizons from at least early Oligocene to late Pliocene. The basic lavas are chiefly tholeiites in Western Australia and olivine-basalts in Eastern Australia, where more alkaline types include olivine-nephelinites, leucite-basalts, trachyphonolites, tinguaites, trachytes, and solvsbergites, while acid lavas, rhyolites, pitchstones, and dacites, occur mainly in S.E Queensland Perhaps Tertiary, are the leucite-lamproites of the Kimberley district, N W Australia.

Diastrophism, thought to be late Miocene or Pliocene, has folded Tertiary rocks in N.W. Australia, where, in the Cape Range anticline, marine Tertiary rocks have been upwarped to 1,200 feet above sea level. In S.E. Australia the marine Tertiary deposits, though commonly nearly horizontal, in places show gentle folding with dips of 10°–20°, while locally they may even be vertical where involved in fault movements. Downwarping has permitted marine transgression, reaching a maximum in Miocene times, to distances from the present coastline of 250 miles in the Murray River basin and probably nearly 200 miles in the region north of the Great Australian Bight. In such downwarped

areas lignites totalling 780 feet in thickness occur in the Latrobe Valley in Victoria, while in other areas marine Tertiary deposits reach thicknesses of more than 2,500 feet. Elsewhere block-faulting has raised them to 900 feet above sea level.

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Fig 1—Anglesea, V (Angleseaan) Fig 2—Balcombe Bay, V (Balcombian)
Fig 3—Batesford, V. (Batesfordian)

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Fig. 1.—Beaumaris, V. (Cheltenhamian). Fig. 2.—Torquay, V. (Janjukian).
Fig. 3.—Kalimna, V. (Kalimnan).

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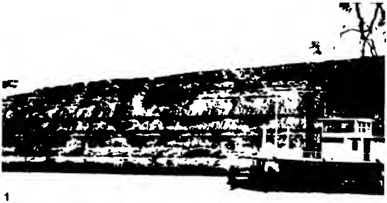

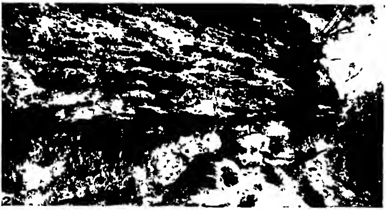

Fig. 1.—River Murray, S.A. (Murravian). Fig. 2.—Glenelg River, V. (Werrikooian).
Fig. 3.—Yallourn, V. (Yallourn Series).

Explanation of Plates.

Plate I.

Fig 1.—Coastal cliffs between Demon's Bluff and mouth of Anglesea River, half a mile east of Anglesea bridge, Parish of Jan Juc, Victoria type locality of Anglesean Stage. View N.E., showing dark Anglesean sandstone overlain by white sands, with rock stack in foreground and anticlinal axis hidden in bay behind projecting point (See p. 25) F.A.S. Photo.

Fig 2.—Coastal cliffs 150 yards north of old cement works, Balcombe Bay, a mile and a half south of Mornington, Parish of Moorooduc, Victoria type locality of Balcombian Stage View S., showing grey marls (*k*) with concretionary limestone bands in lower portion, overlain by ferruginous sandstone (*p–l*) near top of cliff. Fossiliferous beds (*i*) outcrop chiefly on beach floor between fallen blocks of sandstone. (See p 27) F.A.S. Photo.

Fig 3.—Upper quarry of Australian Cement Ltd on left bank of Moorabool River, a mile south south-east of Batesford, Parish of Moorpanyal, Victoria type locality of Batesfordian Stage. View E.N.E., before diversion of river across quarry floor, showing Batesfordian Lepidocyeline limestone (*a*) passing up into white bryozoan limestone (*b*) overlain by darker earthy limestones (*c*) At level of upper talus band these are overlain by Balcombian clays and marls (*d*), followed at the top by ferruginous sands (*e*) (Kalimnan?) white sands (*f*) (Werrikooian?) and a capping of basalt (*g*) in right upper corner (See p 31) F.A.S. Photo

Plate II

Fig 1.—Coastal cliffs 150 yards east north-east of site of former baths (marked by piles), Beaumaris, Parish of Moorabbin, Victoria type locality of Cheltenhamian Stage View W.S.W., showing hard band of sandstone in right foreground, under which is a shell bed (marked by figure near rucksack), with nodule bed about 2 feet below beach level Lower part of cliff is of fossiliferous sandstone (*a*) followed by sandy marl (*b*), upper part of hard ferruginous sandstone (*c*) capped by white sands (*d*) (See p. 33.) Nodule bed outcrops on beach floor from site of baths to far side of boatshed, the anticlinal axis being in line with hotel on cliffs. From boatshed to Table Rock in extreme distance cliffs are of ferruginous sandstone, with Lovenia bed in lower third, capped by white sands at top F.A.S. Photo

Fig 2.—Coastal cliffs opposite Bird Rock (rock stack on left), one and a half miles south west of mouth of Spring Creek, Torquay, Parish of Jan Juc, Victoria type locality of Janjukian Stage. View S.S.W., showing sandy marls from base up to capping of Bird Rock, followed by glauconitic clays ("Chione clays") forming ledge at base of cliff on right, in turn overlain by clays and limestones of upper beds (See p. 39) F.A.S. Photo

Fig 3.—Road-cutting immediately west of bridge over North Arm, half a mile east-north east of Jemmy's Point, Kalimna, Parish of Colquhoun, Victoria type locality of Kalimnan Stage View W., showing, from above, post Kalimnan sandy clays (*l j*), white upper shell bed (*h*) resting on hard sandstone (*g*) and sandy marls with harder bands (*f*) Hard band (*e*) reaches road level at foot of figure Underlying beds are obscured by talus, but outcrop, including lower shell bed (*c*), to right of limit of photograph (See p 41) F.A.S. Photo

Plate III

Fig 1.—Cliffs on right bank of River Murray, half a mile above Morgan, near North-West Bend, South Australia. View N.N.W., showing calcareo-argillaceous sandstones and arenaceous limestones of Middle Murravian, overlain near top of cliffs by Upper Murravian sandstones and capped by oyster beds (See p 43) F. A. Cudmore Photo

Fig 2.—Caldwell's Cliff, eastern end, on right bank of Glenelg River, a mile and three quarters south of Limestone Creek junction, Parish of Werrikoo, Victoria type locality of Werrikooian Stage View W.S.W., showing from above, flaggy and concretionary limestone (*s–c*) overlying Werrikooian shell bed (*b*) resting unconformably on Barwonian bryozoan limestone (*a*) See p. 47.) F.A.S. Photo

Fig 3.—State Electricity Commission's Open Cut, Yallourn, Parish of Narracan, Victoria View S.E., showing 200 ft lignite and 30 ft clays and sands of Yallourn Series (See p 48.) State Electricity Commission Photo

[Proc. Roy. Soc. Victoria, 53 (N.S.), Pt. 1, 1941.]

Art. II.—*Outbreaks of White Spot or Ichthyophthiriasis* (Ichthyophthirius multifiliis Fouquet, 1876) *at the Hatcheries of the Ballarat Fish Acclimatization Society with notes on Laboratory Experiments.*

By A. DUNBAVIN BUTCHER, B.Sc.

[Read 11th April 1940; issued separately 1st February, 1941.]

Contents.

Introduction.

This work has been carried out in my capacity as Biologist on the Victorian Fresh Water Research Committee. This Committee, which is an honorary one, conducts investigations into fresh water problems throughout the State. White Spot is one of the varied problems which have been studied in the three years of the Committee's existence. My own work was carried out in the Zoology Department, University of Melbourne, and two visits were made to the hatcheries at Ballarat.

The parasite responsible for this disease has been introduced into Australia and one certain source is from imported ornamental carp. It is impossible to state the first date of entry; only in recent years has the disease been of any great economic importance. Previous to that it had been observed in private aquaria over a considerable period, frequently causing the death of small exotic fish.

Outbreaks of this disease, on an epidemic scale, occurred at the hatcheries late in the 1938-39 season when yearling trout were infected, and again early in the 1939-40 season when trout fry were infected. The first outbreak occurred on 3rd April, 1939, and the second was reported on 21st November, after having appeared some days earlier. Both outbreaks showed up very suddenly and were severe in their effect. The losses for the two seasons are set out in Table 1.

TABLE I.—Losses caused by White Spot

	Brown Trout.	Rainbow Trout	Total Losses
1938–39	50,000	30,000	80,000
1939–40	275,000	95,000	370,000

The parasite population probably was building up prior to the recognition of the disease and under suitable conditions reached epidemic proportions

This report refers in particular to the second outbreak although mention will be made of the first when it differs in some respect from the second.

Occurrence of the Disease.

Serious epidemics have been reported from time to time in France, Holland, Germany, and in various parts of the United States of America The disease was first recorded in 1869 in the Zoological Garden in Hamburg, Germany, and in France in 1876, where careful observations were made and the name *Ichthyophthirius multifilus* was proposed by Fouquet for the pathogenic organism—(Prytherch 1924)

In October, 1929, an epidemic at the Ballarat hatcheries was reported to be White Spot but the description of the symptoms in the Minutes of the Society does not warrant such a conclusion The outbreak was not investigated on that occasion

An outbreak of White Spot occurred at the Plenty hatcheries, Tasmania, in February, 1933, when trout fry and yearlings died In a report on the outbreak by the Honorary Pathologist of the Tasmanian Salmon and Freshwater Fisheries Commission it is stated that few, if any, of the deaths were caused by the parasite The probable cause was that just prior to the outbreak the sediment at the bottom of the ponds had been stirred up by dragging bluestone bags over the bottom in an attempt to get rid of a heavy growth of weed—(Salmon and Freshwater Fisheries Commission (Tasmania). Report, June, 1933).

In July, 1933, White Spot was reported on young blackfish (*Gadopsis marmoratus*) in a private pond at Heidelberg (Melbourne) This diagnosis was later confirmed

Numerous reports have been received of cases of White Spot on aquarium fish in Victoria and New South Wales.

The disease is also prevalent in Japan. It attacks only fish which are confined to ponds or aquaria, and is never found on those living in lakes and rivers—(Roughley, 1933).

In August, 1937, the disease was reported from Capetown, South Africa It had been introduced with imported tropical aquarium fish An Honorary Fishing Inspector succeeded in infecting a small indigenous fish (*Spirobranchus capensis*) with parasites from imported fish—(Cape Piscatorial Society, South Africa, 1937)

Life Cycle of the Parasite—Conditions Favouring an Outbreak of the Disease.

White Spot is caused by a ciliate protozoan parasite which is whitish in colour and visible macroscopically, the size ranges from one-half to slightly less than one millimetre in diameter The body is round or elongate oval in shape and movement is by an active rotation brought about by the action of the cilia which are arranged regularly in rows "The ciliate fixes itself to the skin and gradually becomes embedded in the epidermis" (Wenyon, 1926)

The life cycle is complicated but for all practical purposes it may be divided into four phases (Fig 1)

The disease derives its name from the appearance of the infected fish The skin may be raised into pustules which are whitish in colour (hence the name "White Spot") over any part of the fish, body, head, fins, tail, gills, etc, in a young form, and over the gills, fins, tail or on any unscaled portion in an older individual Within the pustules are the parasites and they remain there for a period of four to nine days or longer, the period being determined by the water temperature The parasite passes its growing phase in this position Numerous transverse sections have been taken through the pustule and the body wall of the fish, and although there is no doubt that the parasite does increase in size within the pustule, there is no visible evidence of any breakdown of the tissues or of the skin within which the parasites lie. Roughley (1933) states that "Occasionally these blisters are found to contain several of the parasites, which have resulted from the division of the original one into several parts." But after examining in stained preparations several hundred pustules containing very numerous individual parasites this statement cannot be supported According to Wenyon (1926) "There is some doubt as to whether multiplication of the ciliate can take place within the pustules, for the presence of two parasites in a single pustule, as sometimes occurs, may be merely an indication of an invasion of one spot on the skin by two ciliates." In all the material examined from Ballarat the pustules have contained from several up to 40 or more individuals and the occurrence of one or two individuals in a pustule has been rare. The parasite does not lose its locomotory power within the pustule; it may be observed under a microscope to be slowly rotating if

the skin bearing the pustules is stripped from an infected fish which has just been killed. When the pustule bursts the free-swimming forms are liberated into the water; these forms may be called the *Precystic* forms and they constitute the second phase of the life cycle. Experiments have shown that these forms do not reinfect a fish, but after a few hours in the free-swimming state they settle to the bottom of the pond and there encyst, this is the third phase. The process of encystment consists of the secretion of a gelatinous membrane followed by binary fission of the individual. The number of individuals

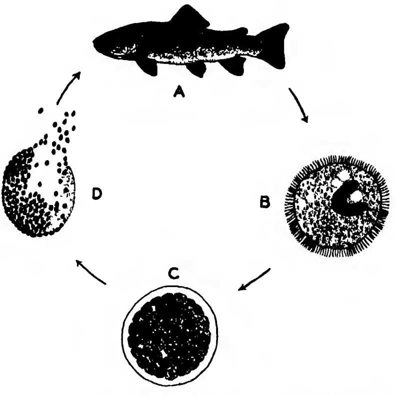

FIG. 1—Diagrammatic representation of the life cycle of parasite. *A*, adult parasites [illegible], *B*, parasite aft[illegible]g fish as a free-swimming pre-cystic form and about to settle to the bottom, *C*, division of the adult into many smaller individuals after formation of cyst, *D*, bursting of cyst, releasing hundreds of minute post-cystic forms of the parasite, which in turn reinfect the fish. (After Prytherch, slightly modified.)

arising from the single parasite which formed the cyst varies. Usually there are several hundred but the number may reach 2,000. Within a few hours the cyst ruptures and the new individuals which may be called the *Postcystic* forms are liberated.

These are again free-swimming and constitute the fourth phase of the life cycle These are the forms which re-infect the fish and give rise, after a few days, to the characteristic pustules

Thus, in the life cycle of the parasite there are two free-swimming phases and two fixed phases All control measures must be aimed at the parasite while in any of its three stages away from the fish, this will be discussed later on. It is usually stated that the parasite is away from the host for a period of 24–36 hours, the time varying according to the temperature Recent work, which will be dealt with more fully in a later paper, has indicated that the parasite may live for several days after it has been liberated from the cyst if the host is not available This fact has to be taken into consideration in all control work

Conditions which favour an outbreak of White Spot are:—(1) High water temperatures, 60°F or greater, and (2) poor water supply

These conditions were fulfilled in the first outbreak Drought conditions had persisted over a considerable period; the water supply to the ponds was poor and temperatures ranging from 58–63°F were a constant feature In the more recent outbreak conditions were somewhat different The water temperatures were fairly high, 62–64°F, but the water supply was excellent, sufficient being available since the commencement of the season It may be seen that conditions favouring an outbreak were not at an optimum, but as against this, in the second outbreak, the fish infected were fry, which are more suspectible to the parasite than are yearlings

In hatcheries the conditions favouring an outbreak are easily attained, and it is noteworthy that from hatcheries have come all the reports of serious epidemics To my knowledge none of any importance have been reported from lakes or rivers "In nature, on the other hand, ichthyophthiriasis is seldom observed, probably owing to the fact that under natural conditions only a very small proportion of the young parasites succeed in establishing themselves on a fish, and consequently the infections produced are so slight that they are overlooked, and the fish is unharmed" (Minchin, 1912) The possibility of an epidemic in a lake is slight and in a river even less so, in these environments, apart from the reason given by Minchin, suitable conditions are less likely to be reached

The disease was more rapid in its effect this season (1939-40) than in the last, the size of the fish in each case again being the probable explanation

While in Ballarat I examined a bottle of water which had been obtained, before my arrival, by dropping the bottle into an infected pond It contained a large number of the free-swimming forms indicating the density of the parasite population

Another point of general interest is the fact that in both outbreaks of the disease there have been a few fish which have survived in the infected ponds. This may be an indication that a few fish attain immunity.

The Source of Infection.

The distribution of the infection in the ponds during the early part of the 1939-40 season was puzzling, and at first threw no light on the probable source. The ponds at the hatcheries are in series, that is, water flows through one pond to the next. Ponds 6, 5, and 4, which are in series (see Fig. 2), and ponds 7-15, also in series, were infected. Pond 7 was the first to show infection in the outbreaks of both seasons, and the disease appeared to be most rapid in its effect in this pond on both occasions. An overflow pipe runs from pond 7 to pond 6, thus interconnecting the two series and providing the explanation for the spread of the disease through them. Ponds 17-46 form a separate unit (all not included in figure). Ponds 25 and 32, coming in series in this unit, were also infected, whilst ponds coming before and after them, and receiving the same water supply, were not infected.

The following possible sources of infection were suggested, and were examined in turn —1 The Gong Reservoir; 2 Lake Wendouree, 3 Some source in the hatchery itself.

1 The Gong Reservoir

This reservoir is the normal source of water for the hatcheries, but there is no evidence of the parasite coming from it. Several reservoirs form Ballarat's water supply, but the water ultimately passes through the Gong. The reservoirs are heavily stocked with English perch, and the Gong was netted, several hundred small fish being obtained. These were examined and none showed any signs of infection. A few fish were also taken from the Kirk reservoir (which supplies the Gong) and these again were clean. Evidence obtained at the hatcheries indicates that the English perch is either non-susceptible or is infected only with difficulty by *Ichthyophthirius multifilus*. A small fish was taken from a pond in which several thousand trout had died, and in which were still large numbers of free-swimming parasites, and yet it showed no signs of infection, and was in perfect condition. Prytherch (1924) after giving a considerable list of species of fish for which the parasite has proven fatal, states that the perch, among a few others which he names, is seldom killed by the disease or affected to any noticeable degree.

2 Lake Wendouree

Water is pumped from the lake to the hatcheries when the reservoir supply is unsatisfactory. All the water leaving the hatcheries runs into the lake, the outlet and the pump-line inlet

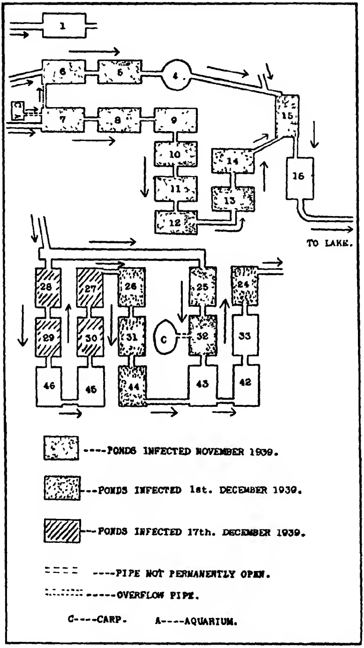

FIG. 2.—Diagrammatic plan of the Ballarat hatcheries, showing only those ponds which are under discussion.

being normally some distance apart During the 1938-39 season drought conditions prevailed and water had to be obtained from the lake. The lake level fell considerably, and to overcome this difficulty a large pit had to be dug from which water was pumped Unfortunately, at the same time, in a further attempt to remedy the poor water supply, the outlet pipe was moved and all waste water was run into the pit. By this means water from the infected ponds ran into the pit and was carried back to the hatcheries. The water to the hatcheries first passes through concrete storage tanks before going to the ponds, and it is the usual practice to place fry in these During the last season fish in one tank became infected The lake must therefore have been the source of infection of this tank, even though the infection in the lake itself may have been derived from the hatcheries.

Apparently the parasite did not carry over the winter in the lake as lake water was used at one period early this season prior to the outbreak and the fish remained clean

Unfortunately, again this season, infected water was run into the lake for two days without first being treated. Lake water has not been used since that date Later, tests of the lake water and methods of treatment of the water running into the lake will be discussed The inlet and outlet pipes from and to the lake are again some distance apart

All evidence points to the fact that Lake Wendouree was infected from the hatcheries and that it is not the primary source of infection.

3 The Hatchery

The third possible source of infection was from fish introduced into the hatchery itself. The only fish in the hatcheries were English perch, carp, and trout, both Rainbow and Brown The perch, as already mentioned, are apparently not infected. A large aquarium of carp has been kept in the hatcheries for some years and this is only a few feet away from pond 7. These fish were examined, and in several cases were found to be carrying the parasites. The pustules were not numerous and no dead fish had been observed. Some time previous to the outbreak a tench had been placed in this aquarium and had been found dead some time later, but it was not examined. Prytherch (1924) states that ichthyophthiriasis is fatal to tench. The carp appear to act as carriers of *Ichthyophthirius multifiliis*. Once these fish were found to be infected all the evidence pointed to this aquarium being the source of infection. Pond 7 is in direct line with the aquarium and this is the pond which has been the first to show the infection on both occasions. Any heavy shower of rain will cause the aquarium to overflow into pond 7, and there is also a pipe connecting the pond and the aquarium, which has been used to empty the latter. Carp have been kept in the aquarium

for some years, but prior to the first outbreak of White Spot, fresh fish had been brought over from ornamental ponds in the adjoining Public Gardens. Japanese carp had been added to these ponds some time before this, and soon after some of these fish had been observed dead or dying This fact had only been casually observed at the time and the fish had not been examined As has already been mentioned, pond 6 is in direct communication with pond 7 by way of an overflow pipe, which explains how the second series became infected Eighty thousand fry were lost early this season in these twelve ponds Only a few carp from the ponds in the Gardens could be examined, and these showed no signs of infection This evidence could not be taken as conclusive as these fish may not have been infected at the time, and larger numbers would have to be examined at intervals

The explanation of the infection in ponds 25 and 32 is not quite so conclusive Next to pond 32 (see fig 2) is a small pond carrying carp This carp pond is not in direct series with the main ponds, but is connected, by means of a pipe which is normally closed, to pond 32 The pipe had not been opened this season Carp from here were examined but appeared clean One dead fish floating on the surface of the pond was also examined, but although indications of infection were observed the fish had been dead too long to permit a definite diagnosis The explanation of the infection in ponds 26, 31, and 44 later in the present season appears to be this When the water level in a pond rises higher than normal, due to blockage of the outlet by silting of the wire screen across it, as occasionally occurs, the water may flow backwards through the inlet channel and thus enter other ponds This is probably the explanation of the December 1st outbreak following on inefficient treatment of the ponds which were infected in the earlier part of the outbreak

Although there is no direct evidence as to how the infection was carried to ponds 25 and 32 in the early part of the outbreak, there are several possible explanations

The parasites may have been transferred by means of gear which had been used in infected ponds This could have quite easily been done before there was any indication of the outbreak The hatcheries are easily entered, and it is known that children interfere with the ponds in the absence of the hatcheries' staff During one of my visits to Ballarat fish were found in ponds to which they could not have possibly moved by way of the water channels. It is possible that fry from the infected ponds could have been transferred to these ponds, which were clean in the early stages of the outbreak of disease. Birds bathe in the ponds, and the parasites may be transferred by this means. Rats also move from one pond to another. A further possible agent is the yabby (cray-fish) which is driven from the infected ponds by the salt treatment

Control Measures.

The cheapest satisfactory means of control is by the use of sodium chloride. Laboratory tests have shown that sodium chloride and potassium permanganate destroy the parasite in its precystic, cystic and postcystic stages. The more detailed work was done with the precystic stage, using different concentrations of sodium chloride. Fifty tests were made, and the results of a number of these are given in Table II.

TABLE II.—Toxicity tests with sodium chloride.

Test	Concentration of NaCl	Number of Parasites Used	Temperature	Time of Cessation of Movement	Remarks
	Per cent				
1	0·5	1	16·1°C		Still alive after 35 minutes
2	0·5	2	16·1°C		
3	1·0	3	16·3°C		Actively swimming for 3–5 minutes, then movement ceased. Recovered within half an hour
4	1·0	3	16·1°C		
5	1·0	6	16·3°C		
6	1·0	1	18·0°C		
7	1·5	1	18·0°C	2 min 10 sec	No recovery
8	1·5	1	18·0°C	4 min 20 sec	
9	2·0	1	18·0°C	1 min 50 sec	
10	2·0	1	18·0°C	1 min 40 sec	Observations made 30 minutes later. No recovery
11	2·0	1	18·0°C	1 min 45 sec	
12	2·0	1	18·0°C	1 min 45 sec	
13	2·0	1	18·0°C	1 min 20 sec	
14	2·0	3	16·[illegible]°C	35 sec	Actively swimming for 15–25 seconds
15	2·0	4	16·[illegible]°C	40 sec	
16	3·0	4	16·3°C	12 sec	No recovery
17	4·0	4	16·3°C	9 sec	
18	5·0	3	16·3°C	5 sec	
19	8·0	5	16·3°C	Instantaneous	
20	10·0	5	16·3°C	Instantaneous	

The action of the sodium chloride depends on the phenomenon of osmosis, the protoplasm being observed to shrink away from the cell wall. In the case of a 1 per cent solution this contraction takes place and movement ceases. In early experiments in which this occurred it was taken as a sign of death, and it was concluded that a 1 per cent solution was effective. When the experiment was repeated and the parasites kept under observation for a much longer period, it was seen that they recovered within approximately 30 minutes.

All the concentrations of sodium chloride shown in Table II are a little too high. The organisms were transferred to the salt solution by means of a fine pipette, and in each case a small drop of water was carried over, thus slightly lowering the concentration of the solution. This small discrepancy would be difficult to avoid, but it does not seriously affect the conclusions. The error is in the right direction, as these experiments were carried out to ascertain the lowest concentration of sodium chloride which would be effective in controlling the parasite.

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There is a point of interest in reference to tests with the postcystic form, sodium chloride gave the osmotic phenomenon mentioned above, but potassium permanganate, although rapid in its action, produced no visible osmotic change

The parasite cannot be brought under control while on the fish, control measures must be directed at the three phases of the life cycle of the parasite when it is away from the host Other workers have attempted control experiments while the parasite was in the pustule, but if the solution used was of a sufficient concentration to destroy the parasite it inevitably led to the death of the fish.

Numerous chemicals have been tried, and some of the reports on their actions have been contradictory The external application of various chemicals in solution kills and removes those parasites that are about to leave the fish, as well as the smallest forms that have burrowed into the mucous coating. Prytherch (1924) records that experiments with copper sulphate, formaldehyde, sodium bicarbonate, sodium chloride and others, have been successful in killing the parasite, but have so weakened the fish that they either die or soon develop fungus growths and bacterial disease, which eventually prove fatal He further states that for external treatment of parasitized fish the use of aluminium sulphate (alum sulphate) in solution is most satisfactory Control work at Ballarat, using sodium chloride and potassium permanganate, has not produced any ill-effects on the fish, although, in the case of the former, the fish were treated for a period ranging from 9 to 14 days. In this case however no attempt is made to reach the parasites while on the fish but to kill them only after they have left the pustules For this reason a weaker solution may be used and this probably explains the absence of ill-effects to the fish.

Barthélémy (1926) states that tests of many chemicals ($KMnO_4$, NaCl, $HgCl_2$, eau de Javelle, formaldehyde, toluene, chloral hydrate, camphor, pyridine, creosote, H_2O_2, thymol) proved useless, the treated fish dying before the parasite Also he advises that the contaminated ponds be drained, exposed to sun and heat and that the hands of workmen and the tools be disinfected in milk of lime or 1 per cent formaldehyde Ammonia and mercurochrome solutions are suggested for ichthyophthiriasis by Mellen (1926)

Roughley (1933) discusses the use of heat as the most effective treatment for killing the parasite in all stages, including when it is on the fish This method obviously can only be applied to aquaria. It has been found in America that the parasite will not long survive a temperature of 46° F, and on the other hand, a temperature of from 85° F to 90° F also soon proves fatal On account of the fact that the temperature of the aquarium is more easily raised than lowered, and also because a temperature of

46° F is a critical one for many goldfish, the higher temperature has been adopted for the treatment of the disease He then states that a 0 2 per cent solution of acetic acid in contact with the parasite will kill it almost instantly, but if an infected fish is placed in this solution for several minutes, the parasites atttached to the fish are quite unharmed by it Similarly he has had an infected fish in a solution containing 25 drops of 2 per cent mercurochrome to the gallon for three days without the parasites on the fish suffering the slightest harm, although such a solution will invariably kill the parasites with which it is in contact in the course of an hour or two

Prytherch (1924) and Barthélémy (1926) both considered that the use of a rapid flow of fresh water was the most practical method of combating the parasite. By this means the free parasites are removed as they drop off the fish, the temperature is lowered, the vigour and resistance of the host are augmented and the development of the parasite is diminished.

Fast running water, although perhaps the most satisfactory method of controlling this disease, is not applicable at the Ballarat hatcheries for two reasons firstly the ponds are connected in series and the parasites would only be driven from one pond to the next; and secondly, all the waste water from the hatcheries is run into Lake Wendouree which is stocked with fish

Sodium chloride is very satisfactory to use, it is cheap, it is effective in controlling the disease and it does not harm the fish in concentrations sufficient to destroy the parasites in their free living stages. Tests were made at the hatcheries as to the sodium chloride tolerance of trout fry Time did not permit of a detailed experiment but the following results are of definite value

TABLE III—Tests for sodium chloride tolerance of trout fry

Concentration of NaCl Solution	Number of Fish	Length of Experiment	Temperature.	Remarks
Per cent				
3 5	3	1 hr 23 min	60° F	Fish distressed and lying on their sides, but not dead
3 0	3	1 hr 40 min	60° F	Two fish normal. One distressed
2 5	3	1 hr. 18 min	60° F	Two fish normal One slightly distressed

Some of the fry at the hatcheries were in poor condition and in the tests using 2 5% and 3 0% sodium chloride solutions, the fish which showed signs of distress in each case were in a weak condition before the experiments were commenced.

The most serious difficulty met with at the hatcheries was to obtain a distribution of the salt solution throughout the ponds. These are of the following average dimensions: 50 feet long, 15 feet wide at the top, 12 feet wide at the bottom and 4 feet

deep Each has a capacity of 12,000 gallons The way in which the difficulty was overcome will be discussed later. The following figures (see Table IV) give the salt concentrations at various positions in a pond The pond had been treated with a bag of salt (approximately 180 pounds) per day for some days previously and three bags had been added three hours before the analyses were made The salt was added by tipping it into the inlet channel so that it went into the pond in solution .

TABLE IV—Sodium chloride analyses in treated hatchery pond

Test	Position in Pond from which the Water Sample was taken	Concentration of NaCl
		Per cent
1	Inlet end, bottom	1 7
2	Inlet end 12 inches below the surface	0 3
3	Middle of pond, bottom	2·5
4	Middle of pond, 12 inches below the surface	0 21
5	Outlet end bottom	3 7
6	Outlet end 12 inches below the surface	0 18
7	Two ponds beyond, in series with first pond, no individual treatment Outlet end, bottom	2·4

These figures indicate how the solution falls to the bottom of the pond, the concentration at the bottom increasing and the concentration in the body of the water decreasing as one moves from the inlet to the outlet end of the pond Analyses were also made in a race which was being treated and the figures were very similar to those given above

The first outbreak of White Spot at Ballarat was noticed on the 3rd April, 1939. It was not at first diagnosed as White Spot as the fish were heavily infected with Saprolegnia. Salt treatment is also used for Saprolegnia and this was applied After definite diagnosis of the disease as ichthyophthiriasis more careful measures were undertaken. On 11th May a report was received that the epidemic was abating and early in June the hatcheries were free of the disease. Although the surviving 20,000 yearlings were clean, the Ballarat Fish Acclimatization Society was advised not to liberate these fish in streams in the State They were held for a time at the hatcheries, and on showing no further signs of the disease, were liberated in Lake Wendouree

The second outbreak was first observed in the middle of November, 1939, and recurred on three occasions. December 1st, 17th, and 27th, with varying degrees of severity.

Early this season the method of applying salt treatment was to tip 3 bags of salt (approximately 12 bags to the ton) into the pond inlet daily and to leave the inlet pipe open. This would give a salt solution at the bottom of the pond of a concentration as shown in Table IV. $KMnO_4$ was also used in some ponds. A layer of concentrated salt solution at the bottom of the pond was partly effective in that it would kill the forms which had

already encysted, and also the forms dropping down to encyst, but some free-swimming forms would not come into contact with the more concentrated sodium chloride.

A visit was paid to Ballarat in the third week of November and it was realized that the methods previously used were not satisfactory. An attempt was made to combine two methods of control, viz.; the use of sodium chloride treatment and the mechanical means of running water. This was achieved by applying the salt treatment and then cutting off the water for several hours, thus permitting an effective action by the salt solution The water was then permitted to flow and the second method of control came into force

This method appeared to have the epidemic under control, but it broke out again on 1st December The explanation is probably two-fold, firstly, the application of the salt was still inefficient, and, secondly, precautions were lifted too early. A point of great importance in all control work with White Spot is that the treatment must be maintained for a considerable period, for the following reasons The parasite may be on the fish for a period of from five to fourteen days, this depending on water temperatures, as was stated in the outline of the life cycle of the parasite. Both outbreaks of disease at Ballarat have occurred at temperatures of 60° Fahrenheit or greater Under such conditions the parasites would probably not stay on the fish for as long as fourteen days—perhaps up to nine days (the times of the appearance of the several outbreaks this season bear this out), although the period would vary. The fish may have been infected on any one of nine successive days so that on applying salt treatment for a short period, only those parasites emerging from the earlier infected fish would be destroyed. The treatment must be maintained over a period of at least ten days and preferably for a longer period if that is practicable

In an attempt to improve the distribution of the salt solution two modifications in the method of the application of the solution were tried. In the first case the solution was made up in the pump well which supplied the ponds, and in the second, the form of the inlet pipe was altered The inlet pipe is normally just a little lower than the level of the top of the pond and the water enters in a single jet. An inlet pipe based on a form used in the United States of America was now introduced (see fig 3) The pipe now went to a depth of 2 to 3 feet into the water and the end of the pipe was plugged. Several holes were bored into the pipe and by this means a greater distribution of the inflowing water was obtained throughout the depth of the pond.

The circulation of the salt solution was still not satisfactory and another outbreak of the disease occurred in different ponds on the 17th December. A further visit was paid to Ballarat and

another attempt was made to surmount the difficulty of circulation The inlet pipe which had been previously modified was

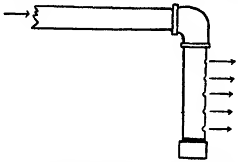

Fig 3 —Modified form of inlet pipe for hatchery pond

elaborated still more (see fig 4) The pipe was lengthened and again holes were bored at intervals The end was plugged and the pipe was now laid along the bottom over the full length of the pond.

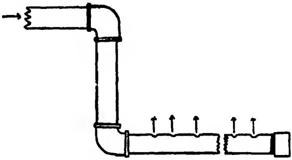

Fig 4 — Second modified form of inlet pipe for hatchery pond

Considerable convection currents were obtained by this means and the circulation was appreciably increased All the infected fish in the hatchery ponds were isolated in a single pond supplied with a pipe of this type. Treatment was first commenced by using 6 bags of salt per day, and this was continued for nine days The quantity of salt was then reduced to 4 bags per day, and the treatment was carried on for another four days. On the 27th December it was reported that the pond was clean and that there were no further losses. Salt treatment was persisted with and on the 12th January, 1940, the fish were still free of the parasite.

Many of the clean fish, that is fish which had not previously been infected, had been isolated in the hatching boxes. These boxes have no connexion with the ponds and no infection could by any means reach them from the ponds by way of the water system On the 25th December it was noticed that these fish were infected with White Spot The only possible explanation is that gear which had been contaminated from infected ponds had been used in the hatching boxes The warmer weather would give more favorable conditions for the outbreak These fish also were clean on the 12th January, eighteen days after the infection was first observed, having responded to treatment with sodium chloride. This period is longer than the necessary quarantine period so a favorable conclusion may be drawn. A further report was received from Ballarat on the 23rd January stating that the disease had been brought completely under control, and that the type of pond inlet pipe illustrated in Fig 4 had proved to be very satisfactory

As has already been mentioned, sodium chloride is a means of control both for White Spot and a disease caused by the fungus Saprolegnia sp Saprolegnia played an important role in the White Spot outbreak of the 1938-39 season. As far as is known it cannot attack a healthy fish and there must be some injury for the fungus to become established The pustules of ichthyophthiriasis supply the necessary injured surface. Following on the first outbreak the fungus was very wide spread and must have been responsible in part for the death of the fish. That the protozoan parasite can itself cause the death of the fish has been well illustrated in the outbreak late in 1939, when the hatcheries were practically free of fungus

There has been some doubt as to whether the cyst of *Ichthyophthirius multifiliis* can withstand desiccation, and as this is a point of great practical importance, tests were carried out. Cysts were isolated and placed in drops of water and were then allowed to dry off in the air They were moistened again on two successive days and kept under observation. It was seen that the parasite cannot survive in the absence of water

Recommendations for the Diagnosis and Treatment of White Spot.

1. If fish are dying in numbers and are showing the symptoms of White Spot, place a few of the dead fish in a tube of water. If the fish are infected with *Ichthyophthirius multifiliis* the parasites will emerge from the pustules within a few hours and can be seen moving around in the water. These parasites are large for Protozoa and can be distinguished macroscopically as

small white roundish objects moving slowly around This test is applicable to hatcheries where laboratory equipment is generally lacking.

2 Isolate infected ponds by cutting off the water and treat with sodium chloride, as suggested in the discussion on control methods It is of great importance that the treatment be maintained for a period of from ten to fourteen days, preferably longer if it is possible

3 After treatment of the infected ponds for this period examine samples of the water at intervals for the free swimming parasites, and if they are still present give further salt treatment Empty the ponds and allow them to dry out before using again A further precaution would be to spray the sides and bottom of the empty pond with a concentrated solution of sodium chloride

4. If waste water from infected ponds does not run into the drainage system but into a lake (as is the case at Ballarat), it must first be treated with sodium chloride If the waste water leaves the hatchery by way of a race, it is advisable to break down the rate of flow to permit of more effective treatment This may be done by placing bags in the race, these acting as a baffle

5 Sterilize all gear such as nets, dipping nets, etc, after use in an infected pond This may be done by dipping the gear in a concentrated solution of sodium chloride This precaution prevents the transfer of parasites from one pond to another

6 Destroy all carp in the hatcheries and sterilize the ponds and aquaria which contained them. In future no carp should be brought into the hatcheries, this statement applies to all fish hatcheries. As far as is known, carp is the original host of the parasite, and in many cases it acts only as a carrier of the disease and suffers no ill-effects

7 If it is possible, destroy all carp in the vicinity of the hatcheries In the case of the Ballarat hatcheries this applies to the fish in the adjoining Public Gardens

8 If the source of the water supply is suspected of carrying infected fish it may be tested in the following way. Pump the water into isolated ponds containing trout fry or yearlings and keep these ponds under observation for the appearance of the disease If possible, this should be done for a period of fourteen days, and if it is practicable, several ponds should be used, filling them successively at intervals of two days By this means the period of observation may be extended over a period of from three to four weeks

9. As the efficiency of the salt treatment depends on the complete circulation of the sodium chloride solution throughout the pond, it is essential that a satisfactory method of water circulation

be devised. As in most cases hatchery ponds are of a considerable size, it is suggested that an inlet pipe of the type illustrated in Fig. 4 be installed. In the absence of disease this type of pipe would still be of service, as the improved water circulation would benefit the fish.

10. It is suggested that a quarantine be applied to all exotic aquarium fish coming into the Commonwealth. The fish should be isolated for a period of three weeks, and if within that time there is no appearance of the disease, they could be declared as free of Ichthyophthiriasis This measure, while assisting to keep this disease in check, would not greatly interfere with private aquarium owners; valuable fish would still be obtainable, while in all probability the rubbish would be kept out.

Summary.

Outbreaks of White Spot disease of fish (caused by a ciliate protozoan parasite, *Ichthyophthirius multifilis* Fouquet) have occurred at the Ballarat Hatcheries in two successive seasons; yearlings being lost late in the 1938-39 season and fry early in the 1939-40 season

The life cycle of the parasite is discussed, as it has important bearing on the methods of control.

Conditions favouring an outbreak of the disease in epidemic proportions are considered

The source of infection is found to be from carp which had been introduced into the hatcheries prior to the first outbreak These fish had been in contact with Japanese carp which are probably the source of the disease in this country.

Control measures are discussed, the use of sodium chloride being dealt with at length.

Recommendations are made as to treatment of and safeguards against this disease.

Acknowledgments.

In conclusion I would like to thank Mr. J. A. Thomas, of Ballarat, for the hospitality he extended me on my visits to Ballarat; Mr. G. W. Cornell, of the Ballarat School of Mines, for information with which he supplied me and for his valued assistance in determining sodium chloride concentrations; and to Mr. H. Coulter, of the Hatcheries, for his assistance.

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[PROC. ROY. SOC. VICTORIA, 53 (N.S.), PT. I., 1941.]

ART. III.—*The Place of the Genus* Styliolina *in the Palaeozoic Palaeontology and Stratigraphy of Victoria.*

By EDMUND D. GILL, B.A., B.D.

[Read 11th April, 1940; issued separately 1st February, 1941.]

Contents.

Historical.

In 1904 Chapman (1904) described specimens of *Styliolina* from the Upper Yarra District as "*Styliola fissurella*, J. Hall, var. *multistriata*, var. nov." and figured a specimen which is now in the National Museum, Melbourne, as the type of the variety.

In 1912 Chapman (1912), describing fossils for the Geological Survey of Victoria, recorded "*Styliola fissurella*, J. Hall, var. *multistriata*, Chapm." from shale on the spur between Jordan River and B.B. Creek.

The following year Chapman (1913) referred the *Panenka-Styliola* beds to a new horizon, which he termed "Tanjilian." He considered this stage to be above the Yeringian series, and to be Upper Ludlow or Lower Devonian in age.

Chapman (1914) recorded the occurrence of "*Styliola fissurella* Hall, var. *multistriata* Chapm." from Howe's Creek Quarry, Loyola, near Mansfield.

Whitelaw (1916) described the geology of the Wood's Point District, and recorded the presence there of *Styliola fissurella* var. *multistriata*.

Kitson (1917) reported from the Powlett Plains District, South Gippsland, the presence in shales of pteropods like those of the Upper Yarra District. These were obtained from a bore at a depth of 660 feet, and were later identified by Chapman (1924) as *Styliola fissurella*, var. *multistriata*.

Junner (1920) grouped the beds of the Walhalla-Wood's Point District which contain *Styliolina* under the name "Panenka Beds" and gave their stratigraphical position as underlying the basal grit of the Walhalla Beds. Both the Panenka beds and the Walhalla beds he classified as "Yeringian (Upper Silurian)."

Chapman (1924) amplified his 1913 hypothesis of a Tanjilian stage above the Yeringian one, and after a discussion of the flora and fauna of the strata, expressed the view that they were almost certainly Devonian in age.

Skeats (1928) showed that the *Panenka-Styliola* beds are below the western basal grits (Yeringian) of the Walhalla Synclinorium, concluding that the Jordan River (Tanjilian) beds are therefore older and not younger than the Yeringian beds (as Chapman had asserted). Skeats proposed the discontinuance of the term "Tanjilian." He also recorded the occurrence of *Styliola* on the Thomson River.

Edwards (1932), when describing the rocks of the Warburton District, referred to the presence of *Styliola* in the Upper Yarra District.

Chapman and Thomas (1935), in a systematic description of the Silurian rocks of Victoria, supported the findings of Skeats (1928), but omitted the Tanjilian series from the sequence (p. 107).

Thomas (1939), in outlining the structure of the Palaeozoic rocks of Victoria, claimed that the *Panenka-Orthoceras-Styliola* association constitutes a reliable marker horizon. He mapped these beds with the Yeringian series.

In 1940 the author (1940) recorded *Styliolina* from Coldstream, a locality in the type Yeringian area.

Palaeontological.

HISTORY OF THE GENUS STYLIOLINA.

Until the year 1864, the fossils now accommodated in the genus *Styliolina* were called *Tentaculites*. In that year Professor Ludwig (1864) referred these smooth "Tentaculites" to the genus *Styliola* of Leseur. In the succeeding years Richter (*vide* Barrande, 1867), Barrande (1867), Hall (1879), and others referred these shells without annulations to *Styliola*, and so the genus became established in Palaeozoic palaeontology. In 1884 Karpinsky (1884) gave reasons for believing that the Palaeozoic Styliolae are distinct from the more recent forms, and he suggested for the former the name *Styliolina*. "*Styliolina* is distinguished from *Styliola* by the form of the embryonal bulb, the lack of longitudinal furrows and thorn-like processes about the stoma and the presence of longitudinal incised lines" (Clarke, 1885). This distinction is now generally accepted among palaeontologists.

ZOOLOGICAL RELATIONSHIPS OF STYLIOLINA AND TENTACULITES

The re'ationship of these genera, and the classification of *Tentaculites* as a Pteropod, have been called in question by some (*vide* Reed, 1906, p. 124; Zittel-Eastman 1913, p. 569). Referring to the bulbous apex of *Tentaculites gracilistriatus*, Hall (1879, p 174) wrote, "This minute bulb is so precisely like that . in recent forms of *Styliola*, that I cannot doubt that it is of precisely similar character and significance" The same author (p. 177) quoted Barrande as saying "These two genera seem then to disappear at the same time, which renders their reciprocal relations more marked" The possession of a bulbous protoconch by both these genera is an important structural link Both these forms are pelagic and their environmental association should be noted. Shells of like proportions belonging to these genera, and in similarly immense numbers, are found associated in the same beds even when other fossils are apparently absent. We may infer that, because they thrived in the same environment even when other forms of life were reduced, that they were physiologically similar.

The genus *Tentaculites* is distinguished from that of *Styliolina* by its possession of annulations on the shell. The two genera, however, are not always easily separated. There are intermediate forms difficult of classification, such as *T. intermedius* Barrande (see also *Styliolina fissurella* var. *obsolescens* Hall).

DETERMINATION OF THE VICTORIAN FORM

Styliolina is a genus difficult to divide into species satisfactorily. Barrande writes, "As a result of the diminutiveness of the forms named and the almost complete absence of ornament on their surface, one finds the chief difficulty is to establish their specific independence." Hall agrees (1879, p. 175). Because these shells have no specialized structure, almost the only data for specific separation are:—

1. Proportions of the shell
2. Ornament on the shell
3. Size of the shell

1. The proportions of the shell seem to provide one of the surest means of distinguishing different species Chiefly on this basis, for instance, Hall established his *Styliola obtusa* and *S. fissurella* var. *strigata* (Hall, 1879).

2. The ornament on the shell is sometimes significant, but generally is a rather variable character. Smooth, transversely striate, longitudinally striate, and both transversely and longitudinally striate forms are found in the same species, viz., *S. fissurella*.

The longitudinal fissure so often observed in *Styliolina* and the accompanying *Tentaculites* is commonly explained as a fracture or indentation produced by pressure in the rock. This explanation has been given by Hall (1879), Swartz and Prouty (1923, p 490), and Prosser and Kindle (1913, p 300). The shell-substance of *Styliolina* is very thin and therefore some degree of collapse is to be anticipated It is noticeable that the fractures are usually in the centre of the shell as they appear on the surface of the rock This can be explained as due to pressure operating vertically to the bedding plane. As often as not the fracture is on the upper surface of the shell. If this depression were natural, then it would be expected that the flatter, depressed side would come to rest on the sea-floor with the rounded side uppermost, and very rarely vice-versa. Some shells have the fracture on both upper and lower surfaces. Specimens occur in which the shell has not collapsed. The author has made sections of such a specimen from Muddy Creek, and observed a fully circular cross-section (cf Ludwig, 1864, " von rundem—nicht eckigem—Querschnitt ') Hall (1879), after referring to the fissure observed in the *Styliolina* shells collected from the shales, wrote, " When occurring in the calcareous bands, this feature is not characteristic "

3 *Styliolina* is usually a minute shell from two to three millimetres long, but a large form (about 45 mm long) is recorded from the Middle Niagaran of America (Swartz and Prouty, 1923). In this case, size is a specific character. It is also a specific character of *S. spica* Hall (*vide* Grabau, 1889).

The specimens of *Styliolina* so far collected in Victoria apparently all belong to the same species. They agree in proportions, ornament (where present) and size with *S fissurella* (Hall), a form having a very wide geographical distribution in North America. Chapman (1904) determined specimens of *Styliolina* from the Upper Yarra as *S fissurella*, but regarded them as differing in a varietal manner from that species, and called them *S. fissurella* var *multistriata* He wrote: " The Victorian specimens cannot be separated specifically from Hall's *S. fissurella*, but differ from it in a varietal manner, by having the surface marked with very fine and regular transverse lines of growth. The American specimens are very variable as to ornament, but they do not show so constant a character in the lineation of the shell as do our specimens " The present writer doubts the validity of this variety. It should be noted that transverse striae on North American specimens of *S. fissurella* are common and characteristic, as the following quotations show:—

> " Annulated above and smooth near base." (Hall, 1843).
> " Surface often smooth and without any visible ornamentation so far as can be determined; or with fine striae of growth, which are unequally developed on different parts

of the shell; also with fine longitudinal striae, which may be present with or without transverse striae." (Hall, 1879, p. 178).

"Transverse and sometimes longitudinal striae." (Grabau, 1899).

"Surface smooth, marked only with fine lines of growth." (Grabau and Shimer, 1909)

"The Maryland specimens are smooth impressions except that the larger ones show very faint remains of transverse striae" (Prosser and Kindle, 1913)

Some of Hall's figures of transversely striated specimens of *S. fissurella* (*vide* Hall, 1879, Plate XXXI A, figs 4, 8, 10, 13, 15) are strikingly like our Victoria form Chapman's figure (1904, Plate XXXI, fig 4) shows the striations as very closely approximated to one another. The photomicrographs (Plate IV, figs 2 and 3) accompanying this paper show that to be inaccurate The spacing of the striae is comparable with that seen on Hall's Figs 8, 13 and 15

Hall describes a number of varieties of *S. fissurella*, but makes no variety dependable on ornament alone because this is so variable a feature The present writer regards the striations on our Victorian specimens as but growth lines and of no special morphological significance

Chapman (1904) regarded the transverse striations as a constant character However, large numbers of specimens, collected from numerous localities, were examined, and were found to possess smooth more often than transversely striate surfaces In view of the foregoing considerations, it is suggested that the variety lapse into synonymy with the species.

Hall (1879, p. 177) remarks that some specimens of *S. fissurella* are scarcely distinguishable from *S clavulus* (Barrande) The Victorian forms of *S. fissurella* are mostly not so slender as the specimen of *S clavulus* figured by Barrande (1867, Plate 14, figs 28, 29) and taper fairly evenly to the apex, which the latter species does not do. Further, *S. clavulus* always has a smooth test, while the Victorian specimens sometimes have transverse striae. Nevertheless, like Hall, the author has observed specimens of *S. fissurella* which are difficult to distinguish from *S. clavulus*.

FAUNAL ASSOCIATIONS.

Throughout the world *Styliolina* is usually accompanied by *Tentaculites* of like size and proportions, and in similarly large numbers. In U.S.A. the associated species with *S fissurella* is generally *T. gracilistriatus* (Hall, 1879, etc.). In Canada *T. gracilistriatus*, *T. bellulus*, and *T. attenuatus* are recorded as in association with *S. fissurella* (Stauffer, 1915; Dyer, 1931; Fritz, 1939; etc.). In Cornwall *Tentaculites* sp. is recorded with

Styliolina sp (Fox, 1900; 1905; etc.). In Bohemia *T. elegans* occurs along with *S. clavulus* (See Barrande, 1867, for Bohemia and other European areas). In the Northern Shan States *Styliolina* cf. *laevis* is associated with *T. elegans* and *T.* cf. *ornatus*. In Victoria *T matlockiensis* Chapman is commonly found with *S fissurella*. In addition *Panenka gippslandica* McCoy and various orthoceracones are characteristic faunal associates of *Styliolina* here in Victoria. Plant remains are also very common in the series, although they do not actually occur in the same bed as *Styliolina* in any locality, as far as is known

EMENDED DESCRIPTION OF *Tentaculites matlockiensis* CHAPMAN.

The fossil described by Chapman (1904) as *Tentaculites matlockiensis* is a poorly preserved specimen, and the collection of well-preserved material now makes an emended description desirable A hypotype (from Muddy Creek, Wood's Point Road, 11 miles east of Warburton) is now presented (Plate IV., fig. 5). The specimen is in the National Museum, Melbourne (Reg No. 14089) Chapman's original description was as follows.—

"Shell conical, tapering, but broader at the open end than is usual in this genus Shell substance thin, as in Styliola, but having distinct annuli, as in the typical forms of Tentaculites. Apical portion bulbous, sometimes apiculate, and occasionally with an overhanging flange. Margin of the orifice undulate, and with a vertical slit or sinus in a line with the median depression of the shell-surface. A transverse section of the shell shows it to be thinner in the neighbourhood of this depression, and the example figured has a tubular enclosure which has the appearance of a small siphuncle or ventral canal The proximity of this tube to the wall of the shell seems, however, to be unfavourable to the idea of its relationship to the Cephalopoda, to which it might otherwise point On the other hand examples are not unknown where a smaller shell is found enclosed in an adult specimen, and from the relative diameter of our section, the slice was apparently taken across the shell, not far from its apical end, where the enclosed shell would have a much smaller diameter. The first third of the shell is generally smooth, afterwards becoming annulated with thin salient ridges, the intercostal spaces being concave The annuli cease near the marginal extremity, and the shell-surface bears numerous, vertical, superficial wrinklings pointing to an affinity with the vertically striated species of the genus"

Description of hypotype. Shell minute, acicular cone, tapering from the stoma to the apex rather slowly for the first third of length of shell, then more rapidly for the remainder. Circular in cross-section, thin-shelled (so that the specimens are usually crushed, displaying a fissure similar to that in the accompanying *Styliolina* shells) About 70 rounded annulations which are wider than the interspaces so that the mould shows thin ridges between the troughs formed by the annulations Annulations more crowded at apical end than at stomatic end.

Comment · The margin of the orifice is not undulate as originally described, the unevenness of the margin being due to the incompleteness of the specimen. The type (Plate IV., fig. 1) is apparently an internal cast—hence the smoothness of part of

the shell and the faintness of the annulations Comparison may be made with the photomicrograph reproduced with this paper (Plate IV., fig. 4). The stomatic end of this specimen shows the internal cast, while the breaking away of the cast reveals the external mould at the apex. On the same slab as the type specimen and on another slab on the same plaque in the National Museum there are impressions of shell-fragments showing clearly the typical ornament of the species as referred to in the emended description. There are also poorly preserved specimens of *Styliolina fissurella.*

Tentaculites matlockiensis is of similar size and proportions to *S. fissurella* and it occurs in similarly large numbers with it. The species is comparable with *T. elegans* Barrande in size and proportions. However, *T. matlockiensis* has much more numerous annulations, and the characteristic longitudinal striation of Barrande's species is absent The more numerous annulations on a shell of similar size means also that the interspaces are different in the Victorian species from those of the Bohemian species. Besides its occurrence in Europe, *T. elegans* is known from Burma (Reed, 1906, pp. 124-125)

T matlockiensis may also be compared with *T gracilistriatus* Hall which is a frequent associate of *S. fissurella* in North America. In *T. gracilistriatus* the annulations are subequidistant, those towards the apex being more distant and more subdued In *T. matlockiensis* the annulations are crowded near the apical end and are not subdued *T. gracilistriatus* has the apical portion of the shell smooth and is ornamented with longitudinal striations. *T matlockiensis* has annulations right to the apex, and no longitudinal striations have been observed.

T. bellulus Hall is another North American species which occurs with *S. fissurella* in that continent. It differs from Chapman's species in being much more attenuate, in having a smooth apical portion, and in possessing acute annulations

Stratigraphical.

OCCURRENCE AND RANGE OF *Styliolina* BEYOND VICTORIA.

Styliolina occurs in rocks of both Silurian and Devonian ages. A large form occurs in the Middle Niagaran of Maryland (Swartz and Prouty, 1923). La Touche (1913) records the genus from the Silurian of the Northern Shan States. Mansuy (1916, 1919) records it from the Devonian of French Indo-China. *Styliolina* occurs in the Devonian of United States of America (Hall, 1879, etc.), Canada (Dyer, 1931; Fritz, 1939; etc). England (Fox, 1900, 1905, etc.), and the continent of Europe (Barrande, 1867, etc.).

OCCURENCE OF *Styliolina* IN VICTORIA.

Styliolina fissurella (Hall) is known from the following localities in Victoria:

1. Railway cutting, Coldstream (Gill, 1940). Chapman (1924, p. 318) has noted scattered specimens in the Lilydale shales. The writer has collected such from Melbourne Hill and Mitchell's Paddock in that same area. *Tentaculites matlockiensis* was also found in the Mitchell's Paddock outcrop. The Coldstream locality, however, is a definite *Styliolina* band with the specimens in immense numbers.

2. Warburton Highway, Killara, in a cutting about ¼ mile east of the turn-off to Killara Railway Station. New locality.

3. "Mouth of Starvation Creek" (Chapman, 1904).

4. Muddy Creek, in a road cutting on the Wood's Point road on the west side of the creek. New locality.

5. Between Muddy Creek and McMahon's Creek Village. New locality.

6. McMahon's Creek (Chapman, 1904). This locality was on a steam tram line now out of use. The Wood's Point road was not then constructed.

7. Cutting on Wood's Point road a short distance east of the quarry containing plant remains at Yankee Jim Creek. New locality. This is near the site of the former village of Reefton.

8. Eighteen-mile Quarry (i.e., east of McVeigh's), Yarra Track (Thomas, 1939).

9. Spur between Jordan River and B.B. Creek (Chapman, 1912; Whitelaw, 1916).

10. Mt. Matlock. New recording.

11. Near Platina (Chapman, 1924).

12. Erica District (Chapman, 1924). Mr. Baragwanath informs me that this locality is on the Walhalla-Erica railway line about 3 miles east of Erica, near Cooper's Creek.

13. Thompson River, near Machinery Spur. The locality is 5 chains east of the Thompson River and 20 chains south of the Quarter Sheet boundary (Skeats, 1928).

14. Howe's Creek Quarry, Loyola (Chapman, 1914).

15. Yea-Alexandra District. Dr. Harris and Messrs. Keble and Thomas found *Styliolina* in this area, but the occurrence has not been previously recorded.

16. Powlett River bore (Kitson, 1917; Chapman, 1924).

17. West of Yankee Jim Creek.

STRATIGRAPHICAL RANGE OF *Styliolina* IN VICTORIA.

Styliolina fissurella is very widely distributed in the North American continent, and its presence in Victoria supports the theory of a Palaeozoic Pacific Ocean postulated by Ruedemann (1911; 1927; 1934, p. 22) and others. In addition to this fossil there are many other species in the Victorian "Silurian" (part of the so-called Silurian no doubt belongs to the Devonian) which are the same as, or comparable with, those found in the North American Silurian and Devonian formations. The following have been noted:—

Actinopteria boydi (Conrad).
Anoplia sp.
Atrypa aspera (Schlotheim)
A. hystrix Hall.
A. reticularis (Linnaeus)
Atrypina imbricata (Sowerby)
Bythotrephis gracilis Hall.
B. tenuis Hall.
Calymene blumenbachi (Brongniart).
C. nodulosa (Shirley) = *C. tuberculosa* Salter non Dalman.
Coelospira hemispherica (Sowerby).
Cycloceras bullatum (Sowerby).
Cyrtinopsis perlamellosus (Hall).
"*Dalmanella*" *testudinaria* (Dalman)
Delthyris crispa (Hisinger).
D. sulcatus (Hisinger).
Edmondia perobliqua Chapman cf. *E. obliqua* Hall.
Eospirifer plicatellus (Linnaeus).
Favosites basaltica Goldfuss.
F. gothlandicus Lamarck.
Goniophora glaucus Hall.
Grammysia arcuta Conrad.
G. plena Hall.
Haliserites dechenianus Göppert.
Heliolites interstinctus Goldfuss.
Leiopteria oweni Hall.
Leptaena rhomboidalis (Wilckens)
Lingula lewisi Sowerby.
Modiolopsis nasuta Conrad
Monograptus dubius (Suess).
M. priodon (Bronn).
Nucula lamellata Hall.
N. lirata Conrad.
N. opima Hall.
Palaeantina solenoides Hall.
Palaeoneilo brevis Hall.
P. constricta Conrad.
P. tenuistriata Hall.
Parmorthis elegantula (Dalman).
Plagiorhyncha decemplicata (Sowerby)
Platyceras erectum Hall.
Plectambonites transversalis Wahlenburg.
Retiolites (*Cladiograptus*) *geinitzianus* Barrande.
Rhynchotreta cuneata Dalman.
Stromatoporella granulata Nicholson.
Tancrediopsis spectabilis (Chapman) cf. *T. altistriata* McLearn.
Uncinulus stricklandi Sowerby.

This list can be extended when the faunas of other Australian States and of New Zealand are considered (Vide De Koninck, 1898; Shearsby, 1911, Allan, 1935; Shirley, 1938; Gill, 1939, etc.). Thus *Styliolina fissurella* is only one of a large group of fossils which demonstrates the faunal connexion between the Siluro-Devonian beds of Australasia and those of North America.

In North America *Styliolina fissurella* occurs in strata of Middle and Upper Devonian age In Victoria it occurs in beds of much earlier age, having been found interbedded with *Monograptus* (Skeats, 1928, p. 229). It is interesting to compare a similar occurrence in the Northern Shan States (La Touche, 1913), where *Styliolina* cf *lævis* is associated with *Monograptus riccartonensis* In Victoria, *Styliolina* has also been found in the type Yeringian area (Gill, 1940) on approximately the same strike as the limestone of Cave Hill to which Ripper (1938) and Hill (1939) have attributed a Devonian age Thus *Styliolina* has quite a long time-range in Australia as it has in North America, but in a lower geological sequence The early appearance of *S fissurella* in Victoria, compared with its occurrence in North America, is a character observed in some other Victorian forms Vascular land plants occur associated with *Monograptus* (Lang and Cookson, 1935). Some brachiopods (e g, *Anoplia*) occur earlier here than they do elsewhere These facts invite the theory that for some forms at least Australia was a Palaeozoic evolutional distributing centre (cf Reed, 1906, p 179; Chapman, 1908, p. 8)

When first dividing the "Silurian" of Victoria into Melbournian and Yeringian series, Gregory (1903) included the *Panenka-Styliolina* beds of the Upper Yarra district in his Melbournian division. Chapman (1914, 1924) included these strata in his Tanjilian series, which he regarded as younger than the Yeringian and probably Devonian in age Skeats (1928) has shown the Tanjilian series to be older and not younger than the Yeringian series Chapman and Thomas (1935) agreed with Skeats, but omitted the Tanjilian series from the "Silurian" sequence, apparently including it with the Yeringian series. Thomas (1939), in mapping the structure of the Lower Palaeozoic rocks, included the *Styliolina* beds with the Yeringian. He also stated that the *Styliolina-Panenka-Orthoceras* association provides a good marker horizon Chapman (1913, p. 212) described his Tanjilian series as follows "This series comprises the Panenka shales of Mt. Matlock, and Reefton, near Warburton In the Walhalla District the Panenka shales of the Jordan River series lie on the Walhalla geosynclinal, and abut on Upper Ordovician graptolite beds . . Should the stratigraphical evidence prove this to belong to a distinct stage in Victoria, I would suggest the term Tanjilian, since the Panenka shales are well developed in the district of the Tanjil River, Gippsland."

There is here no clear indication of which outcrop is to be regarded as the type area of the Tanjilian, unless it be that from which the name is derived. The only locality in the Tanjil River area is that mentioned by McCoy (1879), viz., Russell's Creek, which is a tributary of the Tanjil River. McCoy gives that place as a locality at which *Panenka gippslandica* is "common." Mr. Baragwanath, the director of the Geological Survey of Victoria, is of the opinion that the specimens concerned came, in fact, from McMahon's Creek. The Russell's Creek Mining District reaches as far as the headwaters of McMahon's Creek. Murray (1916) claimed to have collected the specimens referred to by McCoy, but he does not mention them in his two earlier reports (1876, 1880), and when he was making the re-survey described in his 1916 report, Mr Baragwanath inquired about the Russell's Creek locality, but Mr. Murray was unable to say where it was. The fossils are recorded (Murray, 1916) as coming from a tunnel, but no tunnel has been located on Russell's Creek. The nearest known tunnel is one under the basalt about 1½ miles south of where Russell's Creek joins the Tanjil River. This is described in Progress Report No. 6 of the Geological Survey of Victoria. Further, it is to be noted that *Styliolina* has not yet been collected from there (*Contra* Chapman and Thomas, 1935, p. 108). Furthermore, the "Tanjilian" as re-defined in this paper is not co-extensive with the series described by Chapman (the Monograptus Beds are removed), and the name "Tanjilian" itself is associated with an error of sequence. The cumulative force of the foregoing considerations seem to provide good practical grounds for adopting Skeat's suggestion of abandoning the name "Tanjilian." I propose therefore that the name "Jordanian" be substituted, as beds of the *Panenka-Styliolina* association have been fully proved and accurately mapped in the Jordan River area (Whitelaw, 1916; Junner, 1920; Baragwanath, 1925; Skeats, 1928) I propose also that the locality "between Jordan River and B.B. Creek" be the type locality for the Jordanian. As already stated, I do not propose that the Jordanian be co-extensive with the Tanjilian of Chapman. Junner (1920), dealing with the beds which Chapman called Tanjilian, separated the *Monograptus* beds from the *Panenka* beds, referring the former to the Melbournian series and the latter to the Yeringian series. The distinction is a sound one. Whitelaw (1916), in the caption of his map of the Wood's Point District, distinguished between—

1. Yellow silky mudstones with *Panenka*, etc
2. Black slates with *Monograptus* sp.

Hall (1906, 1907) has recorded the following graptolites from the beds called Tanjilian by Chapman:—

Monograptus cf. *crenulatus*.
M. dubius.
M. cf. *jaekeli*.
M. sp. (*colonus* type).

Chapman (1924) included these doubtfully in his list of Tanjilian fossils. Chapman and Thomas (1935) have suggested that they point to a Melbournian age. Recently, Harris and Thomas (1939) have identified the following forms from the Yarra Track :—

Monograptus uncinatus var. *orbatus*
M. uncinatus var. *micropoma.*
M. vomerinus.
M. vomerinus var. *crenulatus.*

M. dubius and *M. colonus* are known from the Melbournian of Melbourne itself (Thomas and Keble, 1933) The two varieties of *M. uncinatus* have both been recorded from the Melbournian beds at Heathcote (Harris and Thomas, 1937). *M.* cf. *vomerinus* has been collected from beds of Melbournian age near Yass, New South Wales (Sherrard and Keble, 1937). *M. jaekeli* and *M vomerinus* var. *crenulatus* are not known from any other locality in Australasia (vide Keble and Benson, 1939) The foregoing evidence persuades me that some at least of the *Monograptus* beds are Melbournian. The *Monograptus* beds appear to be comformable with the Mt. Easton Ordovician strata and so Keilorian beds are to be expected between the Ordovician and Melbournian (as re-defined by Thomas and Keble in 1933). Chapman and Thomas (1935) record Keilorian graptolites "including *Monograptus aplini* and *Stomatograptus australis*" from the Jordan River series.

I propose, therefore, that the "Silurian" succession in Victoria be recognized as follows:—

4. Yeringian (youngest).
3. Jordanian
2. Melbournian.
1. Keilorian.

It will be observed that the Jordanian series is more restricted than the Tanjilian series of Chapman

Besides having a characteristic palaeontology, the Jordanian series has a characteristic lithology. The sediments consist mainly of shales (many of which are finely laminated) and of massive felspathic sandstones. Neither of these latter types of rock can be considered characteristic of either the Melbournian or the Yeringian series. They are absent from the Melbournian and Yeringian type areas. Limestones, which are characteristic of the Yeringian, are absent from the Jordanian.

The following Styliolina localities are regarded by the author as Yeringian.—

1 Railway cutting, south of Coldstream railway station.
2. Warburton highway, Killara.
3. West of Yankee Jim Creek.

This locality is about half a mile west of Yankee Jim Creek and 15½ miles east of Warburton on the Warburton-Wood's

Point road. Clear sections are to be seen on the road and on the aqueduct above the road. There are also outcrops on the river banks below the road. The locality represents a Yeringian outlier and possibly the centre of the synclinorium termed by Thomas the McVeigh Synclinorium (Thomas, 1939). The rocks are closely folded, with crush zones and minor faulting. There is a dyke showing on the aqueduct section. On the same section two anticlines and two synclines (*vide* text-figure 1) can be seen in 300 yards, whereas elsewhere the structure consists of broad open folds. This locality occurs between westerly dipping Jordanian beds at Yankee Jim Creek and easterly dipping

FIG. 1.—Syncline in closely folded strata shown on aqueduct cutting west of Yankee Jim Creek, Upper Yarra District.

Jordanian beds at McMahon's Creek. This outlier gives corroborative evidence to Skeats' paper (1928), which describes the "Tanjilian" beds as underlying and not overlying the Yeringian series, as was originally suggested (Chapman, 1924) From the aqueduct and road cuttings (*in situ* and from loose rock) the following fossils have been collected:—

cf. *Hostimella* sp. Abundant.
Zosterophyllum australianum Lang and Cookson.
Styliolina fissurella (Hall). A solitary individual. The species occurs thus at Lilydale.
Spirifer of the *lilydalensis* Chapman type. Abundant.
Anoplia, sp. nov. Abundant. *Vide* Gill, 1940.
Beyrichia cf. *kloedeni* McCoy. *Beyrichia* is not known from the Jordanian but is abundant in the Yeringian.
Tubuliporinid bryozoan (cf. *Reptaria*).
Fenestella cf. *margaritifera* Chapman.
Crinoid stem joints. Common. Crinoids are not common in the Jordanian but are abundant in the Yeringian.

It has been noticed in the localities examined that in Yeringian outcrops *Styliolina* is restricted to narrow bands or occurs as isolated individuals, whereas in the Jordanian it occurs in great numbers through great thicknesses of rock.

Recently, the author (Gill, 1940) discussed the extent of the Yeringian rocks between Lilydale (type area) and Melbourne (type area of the Melbournian). Subsequent work has shown that there is a band of conglomerate north of Ringwood (½ mile west of where the five roads meet on the Ringwood-Warrandyte road) which has decalcified corals, bryozoa, brachiopods, and crinoids, such as are found in the Lilydale district. This conglomerate is probably the base of the Yeringian. This new locality is the southerly extension of the conglomerate mapped by Jutson (1911). It is seen on his map (plate XCII.) along the Consols and 5th Hill anticlines, which are subsidiary structures on the Warrandyte anticlinorium. In places the conglomerate gives way to a heavy sandstone or grit with inclusions of mudstone. A similar rock is found west of Yankee Jim Creek containing the Yeringian fossils already named The *Spirifer*, *Fenestella*, crinoid fragments, and Tubuliporinid bryozoan are common to both localities

Whether Jordanian rocks occur between the Yeringian conglomerate north of Ringwood and the Melbournian rocks further west has yet to be discovered. It should be noted that *Pancuka* cf *cingulata* Chapman has been found at One Tree Hill some miles north on the same Warrandyte anticlinorium (Chapman, 1908). Mr. R. B Withers and the author found in a small road cutting just outside the Watson's Creek State School (north of Warrandyte) specimens of *Anoplia* (which show that the beds are probably Yeringian) and a pelecypod referable to the genus *Posidonomya*. This genus is unknown from the Yeringian strata, but it is not uncommon in the Jordanian beds between Muddy Creek and the McMahon's Creek village in the Upper Yarra District, west of the Yeringian outlier. The presence of *Anoplia* and *Posidonomya* at Watson's Creek suggests an early Yeringian age, i e., not far removed from the Jordanian. This view is consistent with the structure of the area as at present known. That the Jordanian series represents a definite time-period and not just a facies synchronous with the Yeringian elsewhere is shown by the structure of the Walhalla synclinorium where Jordanian rocks appear between the Melbournian graptolite beds and strata with typical Yeringian fossils. The interposed Jordanian series helps to explain the great dissimilarity between the Melbournian and Yeringian faunas. Chapman (1913) writes, "In the Melbournian division, 136 fossil forms are recorded; whilst in the Yeringian there are no less than 206 species. . . . Of the Melbournian and Yeringian series, only sixteen species are in common, showing the division between the two to be well marked, and probably separated by a distinct geological pause in sedimentation." The figures now are approximately—Melbournian, 137 species (this figure is almost the same because, although new forms have been added to the fauna, some localities previously regarded as Melbournian are now classified as Yeringian),

Yeringian, 259 species, and common to both series, nineteen species A large number of Yeringian forms awaiting description further accentuate the difference between the Melbournian and Yeringian faunas. However, the presence of *Panenka* and *Posidonomya* north of Warrandyte shows that possibly there are Jordanian rocks between the basal conglomerate described above and the Melbournian beds further west The unfossiliferous character of the rocks makes the determination of this point most difficult. Another possibility is that the Jordanian beds thin out so as not to appear at the surface in this area, as is the case with the Mt. Useful beds on the western side of the Walhalla synclinorium (*vide* Skeats, 1928, pl. 11.) The boundary between the Melbournian and Yeringian would then be a disconformity

The following *Styliolina* localities are regarded by the author as Jordanian:

1 Between Jordan River and B B. Creek. Type locality for the Jordanian series
2 Erica District (Chapman, 1924)
3 Eighteen-mile Quarry (i.e., east of McVeigh's), Yarra Track
4. East of Yankee Jim Creek.
5. McMahon's Creek (Chapman, 1904).
6. Between Muddy Creek and McMahon's Creek village.
7. Muddy Creek (west bank beside Warburton-Wood's Point road).
8. Starvation Creek.
9. Mt. Matlock.
10. ? Powlett River bore.
11. ? Howe's Creek Quarry, Loyola.

The following localities are regarded by the author as Melbournian:

1. Nineteen-mile Quarry, Yarra Track. The author has collected with *Monograptus* the following forms.—

Baragwanathia longifolia Lang and Cookson.
Yarravia oblonga Lang and Cookson.
Pterygotus sp.
Orthoceras sp.
Ceratiocaridae indet.

2. Twenty-mile Quarry, Yarra Track. At this locality the author has collected *Monograptus* and plant remains. Harris and Thomas (1937) record from here *Monograptus vomerinus* and *M. vomerinus* var. *crenulatus*.

3. Thompson River, near Machinery Spur (Skeats, 1928).

From the foregoing list of localities it may be seen that *Styliolina* ranges in Victoria from the Melbournian through the Jordanian to the Yeringian.

SYSTEMATIC LIST OF JORDANIAN FOSSILS.

The numbers following the names of the fossils are the numbers of the Jordanian localities listed above. The fossils marked with an asterisk are new recordings, and the specimens are in the writer's collection

PLANTAE:

cf. *Hedeia corymbosa* Cookson —3*
cf *Hostimella* sp.—Yankee Jim Creek*.
Zosterophyllum australianum.—3*; Yankee Jim Creek*; 10½ mile Quarry, Yarra Track*.
Indeterminate plant remains are found at numerous localities

ANTHOZOA:

Heliolites sp —Yankee Jim Creek*

CRINOIDEA:

Small stem joints.—7*, Yankee Jim Creek*; 9 mile Quarry, Yarra Track*

ANNELIDA:

Cast of tube —10½ mile Quarry, Yarra Track*.

BRACHIOPODA:

Athyris sp —6*, 7*
Atrypa sp —7*.
Chonetes sp. nov.—6*.
Cyrtina sp —6*.
Lingula sp.
Orbiculoidea sp —6*

PELECYPODA

Actinopteria sp.—1.
Lunulicardium antistriatum Chapman.—5, 9, "Reefton"
Panenka cingulata Chapman.—5.
P. gippslandica (McCoy).—1, 2, 3, 4*, 5, 8, 9.
P. planicosta Chapman.—9.
Panenka sp. nov. (?).—6*.
Paracardium filosum Chapman.—8.
? *Paracardium* sp.—1.
Posidonomya sp.—6*.
Sphenotus warburtonensis Chapman.—"Reefton"

GASTEROPODA:

cf. *Euomphalus* sp.—8 mile Quarry, Yarra Track*.
Hercynella, sp. nov.—7*.
Zygospira sp.—7*.

PTEROPODA:

Coleolus aff. *aciculum* Hall.—7*.

Hyolithes sp.—7*.

Styliolina fissurella (Hall).—1, 2, 3, 4*, 5, 6*, 7*, 8, 9*, 10, 11.

Tentaculites matlockiensis Chapman.—1, 3*, 4*, 6*, 7*, 9

Tentaculites sp (large).—8 mile Quarry, Yarra Track*.

CEPHALOPODA.

Kionoceras cf. *striatopunctatum* Munster—10.

Orthoceras spp.—1, 3, 4*, 5, 6*, 7*.

PHYLLOCARIDA·

Ceratiocaris sp.—1.

Summary.

1 A critical discussion of the genus *Styliolina* is given, and the Victorian specimens determined as *S. fissurella* (Hall).

2 Data are provided concerning the faunal associations of *Styliolina,* and *Tentaculites matlockiensis* Chapman is redescribed.

3. *Styliolina fissurella* is shown to have a long geological time-range in Victoria (as it has in North America), but at an earlier period, viz., Melbournian—Jordanian—Yeringian, which is Lower Ludlow to Lower Devonian.

4. The "Tanjilian" series of Chapman is critically discussed and the Jordanian series proposed. A systematic list of Jordanian fossils is provided A Yeringian outlier in the Upper Yarra District is recorded. A fossiliferous conglomerate which is probably the base of the Yeringian is recorded from north of Ringwood.

Acknowledgment.

I wish to thank Mr. W. Baragwanath, the Director of the Geological Survey of Victoria, for placing at my disposal his intimate knowledge of the Walhalla-Wood's Point area. Dr. I. C. Cookson kindly determined the plants for me. I have also appreciated the kindness of Mr. D. Thomas, B.Sc., and Mr. R. B. Withers, M.Sc., Dip.Ed., in discussing with me a number of the points raised in this paper. The photomicrographs are the expert work of Mr. L. A. Baillôt of the Melbourne Technical College, except one, for which I owe thanks to Mr. F. Chapman, A.L.S.

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Explanation of Plate.

PLATE IV

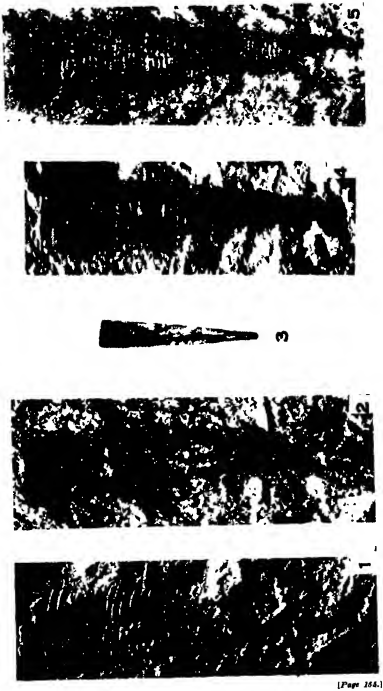
FIG 1—Photomicrograph of *Tentaculites matlockiensis* Chapman Type specimen, National Museum, Melbourne

FIG. 2—Photomicrograph of *Styliolina fissurella* (Hall) Type specimen of Chapman's variety *multistriata*.

FIG 3—Photomicrograph of *S. fissurella* taken by Mr. F Chapman. Note faint striae at stomatic end.

FIG. 4—Photomicrograph of *Tentaculites matlockiensis* Internal mould with external cast showing at apical end.

FIG 5—Photomicrograph of *T. matlockiensis* hypotype from Muddy Creek, Upper Yarra District. National Museum reg. no. 14089.



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[Proc. Roy. Soc. Victoria, 53 (N.S.), Pt. I, 1941.]

Art. IV.—*The Silurian Rocks of the Studley Park District.*

By EDWIN SHERBON HILLS, Ph.D., D.Sc.

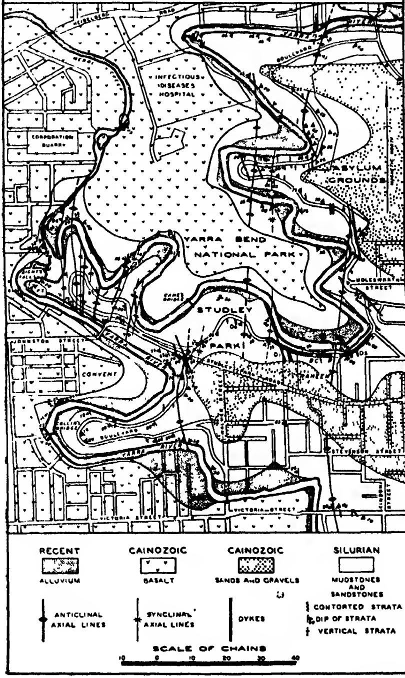
[Read 13th June, 1940; issued separately 1st February, 1941.]

Contents.

Introduction.

The construction of the Yarra Boulevard between Studley Park and Fairfield recently afforded an excellent series of road sections, which the author took the opportunity of investigating while constructional work was in progress, in order to elucidate the complex folding, faulting, and other structural features exhibited by the Silurian strata that form the bedrock of the district. The sections available for detailed study, including the river banks and excavations for roads and tracks, amounted to upwards of 12 miles, although the Silurian rocks occupy only about one square mile in the area mapped. This area is included in quarter-sheet No. 1, N.E. (Melbourne), of the Geological Survey of Victoria, and also in Miss Nicholls' map of the axial lines of folds in the Silurian rocks in the eastern suburbs of Melbourne (Nicholls, 1930). The data available to the present author indicate that the structural information as to dips, strikes, and folds shown on both these maps is unreliable, but only minor changes have had to be made in the geological boundaries on the quarter-sheet. In spite of careful and repeated examination of every outcrop and section, however, it was found impracticable to map all the minor folds, especially in the "crush zone" between Johnston Street Bridge and Dight's Falls. In general, the chief axial lines shown on the map (fig. 1) have been located accurately in the field over considerable distances, though in a few places the delineation of major structures is still somewhat uncertain. For information concerning the general geology of the district the paper by Hauser (1923) may be consulted, the present contribution being concerned only with the Silurian rocks, and the dyke intrusions that penetrate them.

GEOLOGICAL MAP OF THE STUDLEY PARK DISTRICT



Palaeontology.

Fossils have previously been obtained from the track to the Pumping Station (*P.S.* on the map, near Dight's Falls) and also from the spur above the Falls. Hauser listed *Monograptus* sp., cf. *Streptelasma*, *Camarotoechia decemplicata*, *Chonetes melbournensis*, and *Loxonema* sp. from these localities, and Jones (1927) recorded *Monograptus chimaera*, *M. roemeri*, *M. colonus*, and *M. varians* from the track to the Pumping Station. Harris and Thomas (1937) determined *M. crinitus* from this section, and Withers and Keble (1934) described a new species of brittle-star, *Furcaster bakeri*, in a collection made by Mr G. Baker from the loop in the Boulevard north of Johnston Street Bridge. The Rev. E. D. Gill has kindly examined Mr. Baker's collection and also fragmentary shelly fossils obtained by me from the foundations of a pylon north-west of Victoria Bridge, from the northerly extension of these beds on Studley Park Road, and from sewerage excavations in Kevin Street; he has supplied the following list of forms so far identified from the Studley Park district:

PLANTAE:	*Bythotrephis divaricata* Kidston, *B. tenuis* Hall
COELENTERATA:	cf. *Streptelasma*, *Monograptus chimaera* (Barrande), *M. colonus* (Barrande), *M. roemeri* (Barrande), *M. varians* Wood, *M. crinitus* Wood
ANNELIDA	*Keilorites* sp.
ARACHNIDA	*Hemiaspis tunnecliffei* Chapman
MOLLUSCA:	*Pleurotomaria* sp., *Loxonema* sp., *Hyolithes* sp.
BRACHIOPODA:	*Chonetes melbournensis* Chapman, *Nucleospira australis* McCoy, *Plagiorhyncha decemplicata* (Sowerby), *Rhynchatrema liopleura* McCoy, *Spirifer* sp. nov. (?).
ECHINODERMATA:	*Furcaster bakeri* Withers and Keble, *Sturtzura brisingoides* (Gregory), Crinoid stem joints.

In spite of careful searching along the excellent sections north of the tunnel beneath Studley Park road, no fossils have been obtained in this part of the area, and the palaeontological data now available necessitate no change either in the earlier reference of the strata to the Melbournian Series, or their correlation with the *M. nilssoni* Zone of the Ludlovian of Great Britain (see Jones, 1927; Chapman and Thomas, 1935).

Folding.

Miss Nicholls (1930) indicated a synclinal axial line immediately to the east of Dight's Falls, the "Studley Park" anticline just over half a mile further east and extending across the whole of the area dealt with in this paper, and a syncline at the bend in the Yarra River east of "Raheen." As may be seen by inspection of figure 1 and Miss Nicholls' map, the generalizations made by her in extrapolating axial lines from a few observed field apices have not been borne out by more detailed work on the excellent exposures that were available to the present author The axial lines shown by Miss Nicholls trend N. 25° W., whereas actually the trend ranges between N 15° W and N 5° W in the north of the area, to N. 10° E in the south. Thus the Victoria Bridge anticline, which as previously represented appeared to deviate notably from the general trend, is actually one of the major folds of the district, and fits into the tectonic framework in a normal manner (cf. Nicholls, 1930, p 132)

The zone of closely packed minor folds near Johnston Street Bridge is sharply delimited on the east, terminating near the entrance to the Boulevard from Studley Park Road. The southerly continuation of this zone is found north of Collins' Bridge, but it is obscured further south, and also in the north, by late Cainozoic basalt flows. The formation of these complex minor folds is undoubtedly connected with the presence of massive sandstones at Dight's Falls, as was recognized by Miss Nicholls. Most of these minor folds are approximately congruous drag folds (see Hills, 1940, p. 90) ranging in strike from 360° to 22°, and pitching south at angles up to 15° In the river cliff opposite Deep Rock Pool, the strongly disharmonic nature of the minor folding in this section is evident. Miss Nicholls has given two alternative sections to illustrate the structure near Dight's Falls, both based on the assumption that the sandstones at the Falls are not represented in the section along the track to the Pumping Station. These interpretations are, however, open to doubt because of a misreading of the dip at the Falls, which is south-easterly, and not north-easterly as recorded by her. The present author agrees that the structure is in general synclinal, but concludes that the sandstones at the Falls are represented in the west-dipping limb at the western end of the track to the Pumping Station, and that, as is usual in the district, the pitch is to the south, and not to the north, as was suggested (cf. Nicholls, 1930, pp. 131-2).

The folds are of the zig-zag type, asymmetrical, listing towards the east in depth, with vertical or slightly overturned strata in many of the west-dipping limbs, and dips of about 60°–65° commonly occurring in the east-dipping limbs. Throughout the area the pitch is southerly, although in the north many observed fold apices are horizontal. The southerly pitches themselves show

a remarkable range. Thus the Victoria Bridge anticline, on the River north of "Raheen," pitches at 30°, the syncline east of the tunnel under Studley Park Road pitches at 50°, and a drag fold in the river cliff south of the Convent pitches at 90°, the adjacent strata themselves dipping at this angle (fig 2).

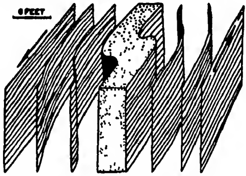


FIG 2—Incongruous drag fold pitching at 90°. River cliff north of Convent.

Numerous other examples of small drag-folds pitching at high angles occur in the district, where, as is also shown by slickensides, considerable bedding-plane slip in directions ranging from parallelism with the dip to parallelism with the strike of the folded strata has gone on The apices of the resultant drag-folds pitch in a southerly sense at angles ranging from 0° to 90°. Drag-folds caused by horizontal shearing movements in already highly inclined strata have been termed " independent " by Derry (1939),

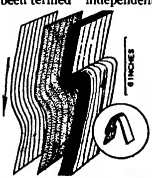


FIG 3—Incongruous drag fold, E. end of Victoria Bridge Cutting. Inset in circle shows diagrammatically the relation of the drag fold to the Victoria Bridge Anticline.

signifying that their development resulted from forces independent of those causing the main folding. If, however, there was a horizontal shearing couple involved in the folding, even locally (see Hills, 1940, p. 58), horizontal bedding-plane slip

would in all probability take place after the beds were folded, leading to the development of the so-called "independent" drag folds. The present author therefore prefers to term such drag-folds "incongruous," signifying that they do not agree with Pumpelly's Rule, but not implying that they are necessarily of a distinct and separate origin from the major folding.

Near the eastern end of the Victoria Bridge cutting, on the south side, there is a small drag-fold (fig. 3) that is incongruous in yet another sense, for, as shown in the inset in figure 3, it apparently indicates movement of the upper strata away from the anticlinal axis, and not towards it as is usual. This arrangement is the same as was observed by Bain (1931) in the limbs of anticlines in limestone, the drag-folds ("flowage folds") being caused by the slipping of strata down the anticlinal limbs, away from the fold axis The same explanation may hold for the present example

Faulting.

As has been remarked by Hauser (1923) and Miss Nicholls (1930) reverse faults are common in the Studley Park district, but the surprisingly large number of such faults present has only been revealed by the new sections, in which a considerable number of normal faults is also shown. The dip and strike of 100 faults could actually be measured, and frequency diagrams representing the direction of dip of these faults have been prepared (fig 4) There are, however, innumerable faults with a

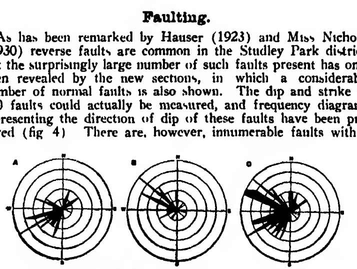


FIG 4.—Frequency diagrams of direction of dip of 100 fault planes along the Yarra Boulevard. *A*, southern area—between *A* on profile *AB*, and Molesworth St.; *B*, northern area—north of Molesworth St.; *C*, composite diagram of all faults. Interval for bearings, 5 degrees; circles unit distance apart—one fault per circle.

slip of the order of an inch, that were not measured, and many others with greater amounts of slip, whose strike and dip could not be determined The fact that westerly-dipping fault planes are by far the commonest is clearly brought out by the frequency diagrams, and is indeed obvious in the field (see profiles, figs. 5 and 6). The average angle of dip of the fault planes is 50°, and, over the whole area, the average strike is 170°

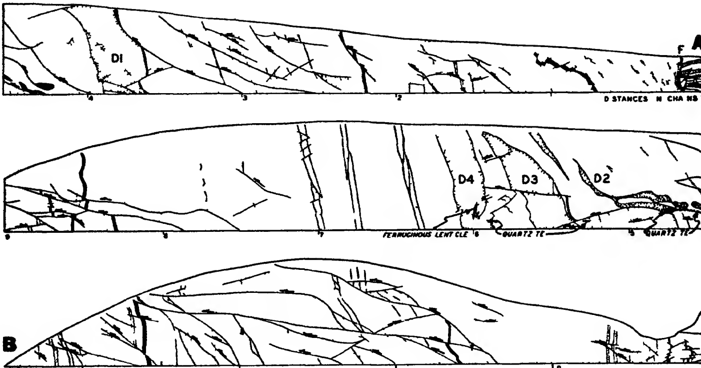


FIG 5.—Profile along the Yarra Boulevard location shown on map (fig 1) by cross-hatching of Boulevard between *A* and *B* Key strata shown somewhat diagrammatically by conventional symbols, e.g solid black dots, or dots between lines Direction or relative movement along faults shown by arrows. *F* fault shown in detail in fig 7 D1–4 dykes

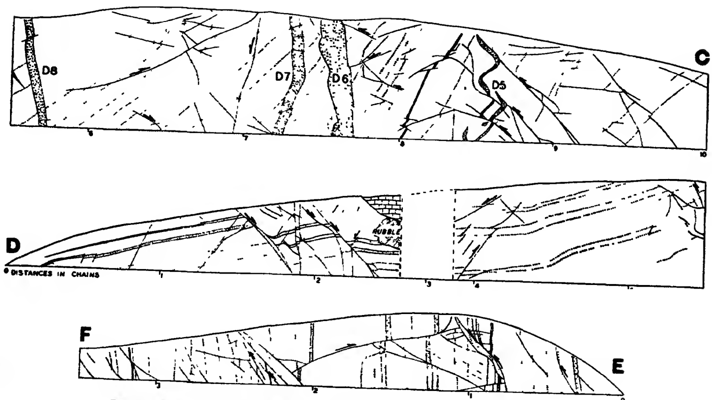


Fig 6 —Profiles along the Yarra Boulevard · location indicated on map by cross-lining between *CD* and *EF*

NORMAL FAULTS

The fault labelled 1 in figure 5 near A brings sheared incompetent mudstones and thin sandstones against more massive sandstones on the west. The latter show apparent drag both upwards and downwards so that the direction of relative movement of the blocks is not immediately obvious. The displacement is however clearly indicated by the pinnate shearing planes (S fig 7) in the incompetent beds adjacent to the fault plane.

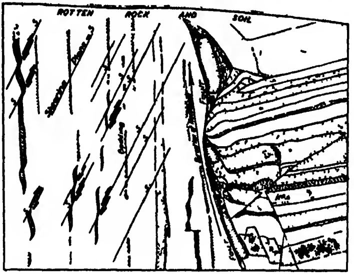


FIG 7—Sketch showing the structural features adjacent to fault *F* (fig 5). The direction of movement along the fault is indicated by the downward opening of the acute angle between the fault plane and the shearing planes S. Length of section 18 feet. West on right.

By analogy with the experiments of Riedel (1929) it is clear that the relative movement of the eastern block was upwards the western downwards this being indicated by the attitude of the pinnate shearing planes in relation to the fault plane. If the fault actually hades towards the west in depth as it does in the section exposed then it is a normal fault. Other normal faults occur near the 2 chain mark on profile CD (fig 6).

REVERSE FAULTS

The great majority of the faults in the district are reverse being shear thrusts (Hills 1940 p 116) that have been formed in already folded strata (see profiles figs 5 and 6). The commencement and termination of some of these faults may be seen in the sections the general arrangement being as shown in figure 8. In almost every case the strata at the end of a shear thrust are flexed then the flexure is broken through and the amount of slip increases progressively along the fault until it reaches

a maximum after which the slip decreases until the strata again are merely flexed and not faulted. Where there is actual separation of the strata the so called "drag" which may be used to

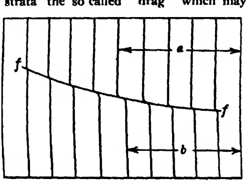


Fig 8—Diagram showing the mode of development of shear thrusts at Studley Park Note the preliminary shear flexing at the ends of the fault plane f f and the increasing slip towards the centre of the fault Measured examples show a b as 20 19

determine the direction of relative displacement of the fault blocks is seen to be the result of the shearing through of the preliminary flexure and not due to friction along the fault plane In many instances the flexing alone is developed along a plane that would if more displacement had occurred have become a fault It is proposed to designate such structures as "shear flexures" In massive strata the "drag" effect results from a small amount of preliminary shear flexing combined with numerous small displacements along subsidiary fracture planes (see top of profile EF above the 1 chain mark also Pl V fig 1)

High angle reverse faults many of which are closely connected with individual folds are common in the "crush zone" near Dights Falls (See fig 10A also Section B in Nicholls 1930 p 134)

Bedding Faults

In all sections there is evidence of marked slipping of strata along bedding planes The existence of definite bedding faults as distinct from bedding plane slip consequent upon the folding mechanisms and from pre tectonic sliding movements which will be discussed below is indicated by the passage of thrust fault planes into bedding planes in many localities

Jointing

Complex jointing is present throughout the area and it is not always possible to decide upon the origin of particular joints observed in the field It is clear however that the majority of

the joints, especially those that may be seen to traverse several adjacent beds, are shear joints, cognate with the reverse and normal faults This is shown by the parallelism of joint and fault planes, and the complete gradation observable between faults and joints, as regards the amount of slip (see Pl V fig 2) Many fault planes indeed commence as shear joints and in other instances parallel shearing planes include examples of both faults and shear joints the slip along the latter not being of sufficient magnitude to enable it to be determined In profile CD, between the 1 and 2 chain marks, a clear example showing two intersecting sets of shear joints, each set parallel to a fault plane suggests that other examples of intersecting joint sets, which are especially characteristic of the sandstone strata in the Melbourne district have a similar origin as incipient complementary shearing planes of tectonic origin It is probable, however, that many of the joints in both sandstones and mudstones are not of tectonic origin but were produced by weathering Thus in several instances successive sandstone beds are independently jointed, each bed exhibiting intersecting joint sets normal to the bedding planes and enclosing a different dihedral angle in each stratum The arrangement which is shown diagrammatically in figure 9, and

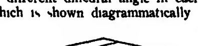


FIG 9 —Diagram showing the nature of intersecting joints sets in adjacent sandstone strata probably due to weathering *A* and *B* laminated sand stones with interbedded lenticles of structureless sandstone In *A* joints intersect at 60° In *B* at 90°

the fact that on close study the joint planes appear to be open gashes, suggest that the joints in the sandstones are caused by expansion of interbedded mudstones in the zone of weathering, due both to mineralogical changes and to swelling of the clay fraction on wetting Such expansion would have been trans mitted to the sandstones owing to the adherence of the strata with one another, and it is suggested that the joints in the sandstones developed as a result Expansion of the sandstones themselves would also have contributed to the process, and removal of the load of superincumbent rock by erosion may also have played a part in the development of jointing in the superficial rocks

Cleavage.

Regional cleavage is not developed in the area, in spite of the close folding to which the rocks have been subjected. At three localities, however, there is a local development. In the anticline along the track to the Pumping Station (3 chains from the commencement of the section near the bridge—see fig. 10) a

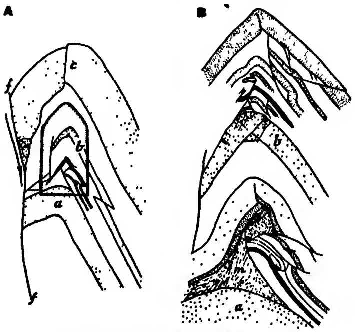


FIG 10.—*A*. Anticline at 3 chains from the commencement of the section near the Bridge, on the track to Pumping Station. Height of section, 8 feet. The shaded area between the massive sandstones *a* and *c* is represented in detail in Fig. 10*B*. See also photograph in Nicholls, 1930, Pl X., Fig 1, *f f*, fault

B Detail between beds *a* and *c* in *A*. Height of section, 3 feet. Note the evidence of flow in mudstones *m*, fracturing of sandstone *b* at the fold apex, and minor shearing and flexing of sandstone layers interbedded in mudstones, the displacements indicating flowage towards the fold apex, parallel to the major bedding planes.

patch of mudstone squeezed along the fold limb near the apex shows a definite cleavage over an area of a few square inches. The cleavage planes are curved, as with typical fracture cleavage in such an environment, and under the microscope they are seen to be rather indistinct shearing surfaces, associated with the minute shear flexures typical of slip-strain cleavage. Cleavage is also present in mudstones in an exposure of a few square yards in the outfall of the Riley Street drain, where there is intense brecciation of sandstones and flowage of mudstones in a zone

of shearing. The most extensive occurrence of cleavage is, however, adjacent to dyke D8 (see profile CD, fig. 6). There, sandstones and mudstones are both cleaved, though the cleavage is better developed in the mudstones. It is parallel to the dyke walls, following irregularities in them, and is well developed for a distance of 5 yards from the dyke on the western side, becoming indistinguishable at 10 yards. On the east cleavage is developed for only one yard from the contact. The strata have been metamorphosed for a distance of about one yard along each wall of the dyke, three zones being distinguishable. Adjacent to the dyke the strata have been rendered soft for about 6 inches. Then there is a zone about one foot to two feet wide in which both sandstones and mudstones have been hardened, and finally the outer zone, up to two feet wide, has been leached to a pale cream colour.

The persistence of the cleavage into the hardened zone indicates that the formation of cleavage antedated the metamorphism of the strata, but there can be no doubt that the cleavage bears some relationship to the presence of the dyke. The latter is unusual in that it contains numerous cognate and foreign xenoliths. Its western face is polished and slickensided, while its eastern is crumbly and shows no evidence of movement. The western face also shows undulations and steps, indicating that it is a fault plane, along which the adjacent country rock on the west has been displaced (relatively) downwards. Under the microscope the cleavage planes in the hardened rock of the zone of metamorphism show no evidence of shear, and their nature could not be satisfactorily elucidated. Finally, it may be noted that mudstone beds are shattered in the hardened zone, though showing regular cleavage without marked shattering further from the dyke, and that near the bottom of the dyke in the road section the metamorphic zones show a clear displacement of about a foot, along a bedding fault.

The interpretation of these data is as follows:—

1. There has been post-solidification faulting along the western contact wall of the dyke.

2. Minor post-metamorphic faulting has taken place along planes intersecting the dyke.

3. The cleavage antedated the final stages of the metamorphic processes.

4. The parallelism of the cleavage with irregularities in the dyke walls, the presence of only one set of cleavage planes, which traverse sandstones and mudstones alike, and the absence of shear flexures on cleavage planes, indicate that the cleavage is not tectonic in origin.

Since it is extremely improbable that such a local cleavage zone should have been developed except in relation to the dyke intrusion, while on the other hand such cleavage zones are absent from all the other dykes in the district, the conclusion is reached that the cleavage resulted from volume changes in the country rock as a result of the permeation through it of solutions of magmatic origin. The possibility that the cleavage resulted from the compression of the strata as a result of the forcible injection of the dyke cannot, however, be rigidly excluded.

Ultimately, the magmatic solutions caused the metamorphism that is now preserved, but the final production of the metamorphic zones post-dated the development of cleavage. It will now be clear that the cleavage along this dyke has no bearing on the question as to whether or not regional compressive forces operated after the dyke intrusions.

Dyke Intrusions.

Numerous narrow dykes, ranging from a foot or even less to about 10 feet wide, traverse the Silurian rocks (Pl. V., figs. 3 and 4). In no place do they intersect the overlying Cainozoic sands and gravels, but nevertheless their age has been regarded as Tertiary, because a fresh dyke at South Yarra proved to be a lamprophyre, and the lamprophyric dykes of the Midlands goldfields are usually regarded as Tertiary (Edwards, 1934). It is not proposed to discuss herein the general question of the age of the dyke and other minor intrusions throughout the Melbourne district or farther afield, but it may be noted that in addition to lamprophyric types (one of which occurs at the corner of Church-street and Alexandra-avenue) there are acid dykes and minor granitoid intrusions in the South Yarra district. These acid rocks are almost certainly of epi-Devonian or Carboniferous age, and there are, therefore, no *a priori* grounds for assuming that all or any of the dykes at Studley Park are Cainozoic.

Most of the dykes are too thoroughly decomposed to permit their original petrological nature to be determined. Some are now plastic clays, white or cream in colour, others are of a very "short" powdery texture, with a residue of fine gritty particles The dyke labelled Do on the map (west of "Raheen") is, however, fresh enough for study. In hand specimen the rock is seen to consist of phenocrysts of simply twinned white felspar up to ¼ in. across and ½ in. long, together with small biotite flakes up to ⅛ in. across (but generally less), set in a mottled ground mass that has a lustrous appearance owing to the presence of numerous small felspar laths. Under the microscope (see fig. 11A) the phenocrysts are seen to be anorthoclase, often in characteristic aggregates resembling glomero-porphyritic texture. A phenocryst of oligoclase, showing very narrow albite twinning lamellae, and rimmed with anorthoclase, occurs in one section

A few red brown biotite plates are present and also small pseudomorphs of a chloritic or serpentinous nature obviously after pyroxene The crystal habit of these pseudomorphs and the measurement of apparent interfacial angles suggest that the original pyroxene may perhaps have been aegirine The ground mass is trachytic with close packed laths of fresh sanidine numerous specks of weathered iron ores and an interstitial green chloritic or serpentinous base This rock is an anorthoclase trachyte resembling extremely closely the anorthoclase trachytes of the Macedon district Actually the closest resemblance mineralogically and texturally is with the so called solvsbergites of that district which in a strict petrological sense are anorthoclase trachytes

The nature of the more decomposed dykes at Studley Park could not be made out so clearly but in D2 there are some felspar laths a few biotite flakes and numerous limonite pseudomorphs after a ferro magnesian mineral D3 is similar to D2 but contains also clots of cream amorphous material The limonite rich lenticle in D4 (see profile AB fig 5) contains phenocrysts of sanidine or soda sanidine and there are also traces of sanidine laths in the groundmass as well as of small altered phenocrysts of a ferro magnesian mineral The dyke D8 adjacent to which cleavage is developed is itself completely decomposed but it contains numerous xenoliths Two different types of xenoliths one a pure white felspathic type another resembling a graphic granite in hand specimen were fresh enough to be sectioned

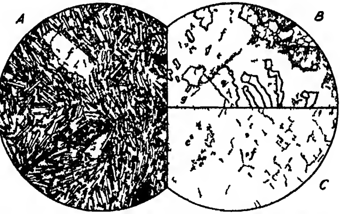


FIG 11 —*A* Solvsbergite (anorthoclase trachyte) dyke *Do* (see Map) *f* anorthoclase *b* biotite *p* pseudomorph after pyroxene

B Graphic soda granite xenolith in dyke *D8* *f* soda orthoclase *q* quartz *g* granular zone along shearing plane Close stippling indicates fine grained felspathic material possibly injected into the graphic soda granite

C Felspathic xenolith in dyke D8 *f* sub rectangular anorthoclase crystals *c* clot containing sanidine lath All x 8

The felspathic type (fig 11c) is a snow white saccharoidal rock consisting entirely of a mass of anorthoclase crystals with an aplitic texture It is related to the lestiwarites of Norway and Finland which are aplites of the alkali syenite series (Johannsen 1937 Vol III pp 25 6) Rounded clots of finer grained material containing minute alkali felspar laths are also present

The other xenolith (fig 11B) consists of an intergrowth of quartz and alkali felspar the latter probably a cryptoperthitic soda orthoclase Originally the intergrowth appears to have been graphic but granulation and recrystallization have affected both quartz and felspar the former showing embayment

It will be clear from the above descriptions that an alkaline suite of rocks is represented among the dykes and the general similarity with the Cainozoic trachytes and solvsbergites of the Macedon district is obvious The petrological evidence therefore strongly suggests that the Studley Park dykes are also Cainozoic In view of this it is important to investigate the relationship between the dykes and the faults especially the reverse faults in the district As may be seen by inspection of profiles AB and CD (figs 5 and 6) dykes D1 D3 and D8 have apparently been displaced by later faults Dyke D5 is however clearly post faulting as it follows the bedding and the fault planes alternately (Plate X fig 3) The question arises as to whether the apparent displacements of the other faults may perhaps be due to the dykes pushing apart already faulted strata Owing to the advanced state of decomposition of the dykes and the absence of metamorphic effects along them (except for D8) it is not possible to investigate displacements of chilled borders or metamorphic aureoles which would yield definite evidence with regard to the relative age of the faults and dykes Where dykes have apparently been faulted (e g D1 D3 and D4) it is perhaps significant that certain of the faults appear to die away within the dykes If the dykes were unaltered when faulted this would not be expected owing to the incompressible nature of the fresh igneous rock The definite evidence that is available (for D5 and D8) indicates that faulting occurred both before and after the dyke intrusions the only certain post dyke displacement being however of small amount

In the ferruginous sands and gravels exposed in the new pit south-east of the tunnel under Studley Park road there are angular pebbles of clay closely resembling that of the decomposed dykes As remarked above the latter do not cut the sands, whose age is certainly Cainozoic but of what period is uncertain They must however have ante dated the Newer Volcanic lavas of the Yarra Valley by a considerable period of time and are usually regarded as Lower Pliocene The dykes are themselves considerably older than these sands and gravels and almost certainly are pre Pliocene

Structural Details in the Silurian Rocks.

PRIMARY STRUCTURES.

The lithological types represented in the district include massive resistant sandstones, softer current-bedded sandstones showing "drift-bedding" according to Sorby's nomenclature (1908) or the "complete curve of current bedding" according to Bailey (1930), together with sandy and fine-grained mudstones. Usually there is a rapid alternation of thin sandy and muddy beds, but in places mudstones are subordinate, as near Dight's Falls, while elsewhere sandstones are locally subordinate

Many of the massive sandstone strata exhibit an indistinct graded bedding, and the tops of current-bedded sandstones typically show ripple or current-mark. Typical current ripples with parallel crests are rare, but dimpled bedding planes, exhibiting "small hollows and protuberances of a few inches in diameter (cf. Jukes, 1872) are very common This structure has been termed "current mark" by Kindle (1917), and is said to be due to irregularities in the sand-laden water-currents, or to the impinging of strong currents along sand bars or at other localities The primary nature of this structure in the Silurian rocks of the Melbourne district, of which there has been some doubt in the past in the minds of Victorian geologists, is clearly indicated by the parallelism of the dimples and swellings in t' · bedding planes with current-bedding curves within the beds. No examples of oscillation-ripple mark have been observed.

SECONDARY STRUCTURES.

The development of a wrinkled, lobate, or manillary base to sandstone strata, where these rest upon mudstone layers, is common in the crush zone near Dight's Falls. The structure is best shown where the incompetent beds are thin, and are interbedded as partings betwen the sandstones.

The deformation of the standstones is usually restricted to two or three inches at most at the base of each bed affected, and involves the underlying mudstones. Both sandstones and mudstones, it is clear, were capable of yielding to the deforming forces by flowage, for the wrinkles and lobes on the sandstone bases have smooth surfaces, and bedding planes in them are curved to accommodate themselves to the impressed geometrical forms. The latter, which range from elongated asymmetrical fold-like wrinkles a quarter of an inch or so apart, through rounded linguoid forms, to mammillate knobs, in places show evidence of having been affected by sliding movements between the strata, in the case of the wrinkles and linguoid forms. The mammillate forms, however, and those illustrated in figure 12A, show no clear evidence of movement.

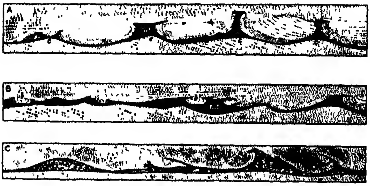


FIG 12.—Types of mudstone injections into sandstone strata Mudstone shown by solid black or broken lines, sandstones stippled. *A*, mudstone injections at above ripple-crests *c* without evidence of differential bedding plane-slip, *B*, balling up of sandstones at *b*, *b*, and development of wave-like mudstone injections with evidence of slight bedding plane-slip *C*, mudstone injections above a flat sandstone surface, with evidence of bedding plane-slip All examples approximately one-third natural size Dip vertical in the field Location 10 yards west of *Bythotrephis* bed, Studley Park Road, near Johnston Street Bridge

The significant data bearing on the origin of these basal sandstone deformations are as follows:—

(1) The structures are developed, so far as was observed, only where sandstones are predominant, e g., in the crush zone between Dight's Falls and the entrance to the Boulevard.

(2) Not every sandstone stratum exhibits the structures

(3) The deformation is shown by certain sandy beds that are only 3 inches thick, which are overlain and underlain by mudstones. In these as in all other examples, the top of the affected sandstone stratum remains undisturbed. The structure is, therefore, not due to sub-aqueous gliding, since this would have thrown the strata as a whole into folds, or developed other large or small scale mass deformations.

(4) Where linguoid or wrinkled surfaces are developed, the direction of movement indicated is not constant from bed to bed, and bears no apparent relationship to the major structures.

(5) Nevertheless, close examination of laminated sandstones and of saccharoidal sandstones showing closely spaced stratification planes shows that there has been a very general tendency for the stratification planes to develop minute asymmetrical waves in which the direction of relative motion indicated by the asymmetry of the waves agrees with the rule for folding—the upper bed moves towards the crest of the adjacent anticline

The interpretation placed upon these facts is as follows:—

(1) For mudstone injections with no indication of differential bedding-plane slip (Type shown in fig 12A).

In this type, injections of mudstone into the overlying sandstone are restricted to the crests of ripple-marks in the underlying sandstone stratum. Clearly, mudstone from the ripple-troughs flowed towards the crests, where it was forced into the base of the overlying sandstone This must have occurred when the rocks were subjected to considerable pressure, and not immediately after the deposition of the basal laminae of the upper sandstone, for if the mud was sufficiently tenacious to remain in place during the deposition of this overlying current-bedded sandstone, its viscosity would not have permitted it to rise under the weight of only an inch or two of sandstone above it Nevertheless, the, sandstone possessed sufficient fluid-plasticity to yield as shown in the diagram It is suggested that the water expressed from the mudstone during gravitational compaction migrated into the base of the overlying sandstone, while the grains were as yet uncemented, so enabling fluid flow to take place in the lower layers of the sandstone The mudstone injections were localized at ripple crests owing to the development of components of the vertical compressional forces on the sides of the ripples In the troughs, the mudstone was subjected to the full compressive force, and it therefore migrated towards the points of least compression, where it was injected into the sandstones in a manner strikingly resembling the experimental salt domes produced by Nettleton (1934) As a result, the basal stratification planes of the sandstones were dragged up along the mudstone injections, producing a mammillate or linguoid surface between the injections

Further indications that the strata were approximately horizontal at the time of development of the structure are given by the fact that the injections above the ripple-crests are normal to the bedding planes, and that all the injection phenomena are restricted to the lower surfaces of sandstones, even in vertically dipping strata Had the strata been vertical when the structures developed, the expressed water could have entered the sandstones on both sides of the interbedded mudstones with equal ease, and the mudstone injections would have shown either a definite relationship to tectonic structures, or have risen under isostatic forces, showing a tendency to assume a vertical attitude. It is suggested that an essentially similar process, involving the expression of water from sandstones, its injection into the bases of sandstones causing them to attain fluidal properties, and the injection of sandstone into this fluid sandy mass under the gravitational force due to the load of superincumbent sediments, was involved in the formation of all the mammillate structures that show no evidence of movement

(2) For mudstone injections into lingoid or wrinkled sandstone bases, indicating movement along bedding planes; also waved stratification planes in laminated sandstones

Movements along the bedding planes may be either pre-tectonic or tectonic in origin The former, it is suggested, may be developed as a result of the differential compaction of sands and muds, especially when the strata are markedly lenticular as they are at Studley Park. We may exclude normal sub-aqueous gliding from consideration because all the minor deformations now under discussion are localized within single strata as units. In sub-aqueous gliding groups of strata are affected together Hadding (1931, pp 380-1) has expressed the germ of the idea that readjustments along bedding planes may take place during compaction, but he classifies mudstone injections almost identical with those indicating movement along bedding planes at Studley Park and elsewhere in Victoria, as resulting from sub-aqueous sliding The two phenomena are, however, essentially different Bedding-plane slip is also developed during tectonic deformation, and when it is remembered that such movements will commence during the early stages of deformation, the difficulty of distinguishing pre-tectonic and tectonic movements will be obvious. So far no criterion has been discovered that might enable a distinction to be drawn, but the virtual restriction of the mudstone injections to the bases of sandstones, and the evidence for great mobility in the latter that the structures afford, strongly suggest that they are pre-tectonic

It should be realized that this interpretation is of a preliminary nature, further investigations of similar structures in other districts are being carried out Already, however, it is possible to indicate that, owing to the virtual restriction of the flowage and injection phenomena to the bottom surfaces of sandstone strata, they can be of considerable use in structural mapping. A further result of the present investigations in this connexion is that in thin sandy strata showing current-mark, where the presence of the complete curve of current-bedding greatly restricts the use of current-bedding as an indicator of the order of superposition of inclined strata, the flat base of the current-marked beds, as contrasted with the waved upper surface, can in many cases readily be distinguished.

The occurrence of true sub-aqueous gliding in the Silurian rocks might be suspected from the presence of marked intra-formational disturbance in places, but the strong shearing, brecciation, and folding of mudstones and thin sandstones lying between more massive strata, seen on the west face of the cliff at Dight's Falls and in the outlet to the Riley Street drain, are of tectonic origin, as is shown by the development of cleavage in the mudstones at the latter locality, and the slickensiding of adjacent massive strata at Dight's Falls.

Origin of Major Structures.

REVERSE FAULTING.

Although the average strike of the reverse faults is 170°, i.e., making an acute angle with the general trend of the axial lines, it is more significant that the faults in the south of the area (fig. 4A) strike, on the average, parallel to the axial lines in this part, while where the axial lines change their trend in the north, the faults change sympathetically in strike (fig. 4B). It, therefore, appears that the faults and the folds are genetically related. The total vertical distance available for study in the district is, however, so small compared with the magnitude of the major anticlinorium involved that it would be unwise to draw any further conclusions as to the mechanics of formation of the faults in general

Some examples, however, are of purely local significance On the north face of the cliff at Dight's Falls, for instance, sandstones and mudstones interbedded between massive sandstones exhibit small-scale incipient imbricate structure with low-angle thrust faults, formed as a result of differential shearing movements of the beds on either side

FOLDING.

Throughout the district, no significant recrystallization of the Silurian rocks has occurred. So far as could be ascertained without the aid of a universal stage, the quartz grains show no marked preferred orientation, and no strain effects even in folds with a radius of curvature of an inch. The plasticity of the strata was therefore not that of a crystalline material, and the folding must have involved only external grain rotation, slip along sedimentary and tectonically developed S surfaces, and positive and negative dilatation. Certain of the sandstones have also yielded by fracture. The mudstones remained capable of flow throughout the folding and faulting; they filled up the spaces formed by the fracturing of the sandstones, and also flowed into the fold apices between the sandstone strata (fig. 10). The sandstones themselves are thickened at the fold apices, measured examples showing two beds thickening from 2½ inches to 3 inches, one from 3 inches to 3½ inches, and one from 6½ inches to 8 inches. These differences in thickness are most probably due to lateral compression, which would result in thinning of the highly inclined limbs and expansion at the apices, the volume changes being brought about by reduction in the percentage of pore-space, and re-arrangement of the grains. This indicates, in the absence of grain deformation, that the grains were not firmly cemented before folding occurred, and, therefore, that the rocks had not been so deeply buried as to have had their pores closed by compaction and recrystallization, or so impregnated with secondary minerals as to have been cemented by infiltration.

The manner of development of shear thrusts, described above, indicates a similar irreversible dilatation of the strata, measured examples on seven faults indicating an average reduction in thickness by 1 in 20 (see fig. 8). Two of these examples gave 1 in 19, two 1 in 20, and one 1 in 22, so the average figure is probably significant

The expansion of sandstones at fold apices also suggests that the local strain ellipse within a particular sandstone stratum, in a plane transverse to the apex and containing the axis of the fold, had its longer diameter vertical. That this was so for the observed sandstones (apices for the massive sandstones at Dight's Falls are not visible) is indicated by one bed that was not capable of sufficient expansion, and yielded by fracturing as is fig. 10B (bed *b*) This fact indicates that not only was the strain ellipse along each fold axis (including many strata) vertical, as is indicated by the flow of mudstones towards the fold apices, but, within each stratum, neutral surface folding (Ickes, 1923), did not obtain Evidently no stratum was sufficiently competent to have acted as a thick plate, capable of lifting the overlying beds. The major stress components within each bed at the fold axes where bedding-plane slip is *nil* were essentially parallel to the regional compressional forces The sandstones yielded by bedding-plane slip along stratification planes as well as along bedding planes, aided by grain rotation. The importance of bedding-plane slip in thick sandstones is admirably illustrated by the Victoria Bridge anticline, on the river east of " Raheen ", where the uppermost laminae of a sandstone bed have been able to slip further than those lower down, and have been raised into a very small subsidiary anticline on the crest of the larger The conclusion is reached, therefore, that the folding involved—

(*a*) flowage of mudstones towards fold apices;
(*b*) bedding-plane slip, and slip along stratification planes in laminated sandstones;
(*c*) thinning of strata in fold limbs, and thickening at apices, by lateral compression.

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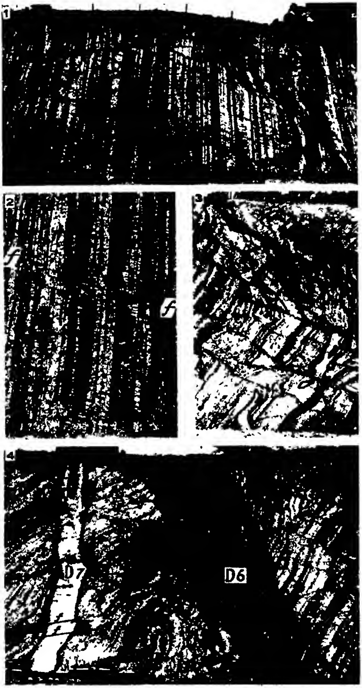
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Explanation of Plate.

PLATE V

Fig 1 Reverse faulting and shear jointing in Silurian sandstones and mudstones Locality about 1 ch mark profile *EF*

Fig 2 Portion of Fig 1 enlarged to show relation between reverse fault *ff* and shear joints.

Fig 3 Dyke D5 (see profile *CD* at 8½ ch) showing the way in which the dyke follows pre existing planes of weakness

Fig 4 Dykes D6 and D7 (see *profile CD* between 7 and 8 ch) *Note the* apparent displacement of the lower part of D7 by post-dyke faulting at *ff* and the inhomogeneity of D6

[*J S Mann photo*

[PROC. ROY. SOC. VICTORIA, 53 (N.S.), PT. I, 1941.]

ART. V.—*A Bacterial Disease of Stocks caused by* Phytomonas matthiolae.

By ROSE MUSHIN, B.Sc.

[Read 13th June, 1940; issued separately 1st February, 1941.]

Introduction.

Early in September 1938, a disease of stocks (*Matthiola incana* R. Br. var. *annua* Voss.) was reported from Brunswick Park, Victoria. The stocks showed a high percentage of diseased plants distributed in large patches amongst the healthy ones. Enquiries revealed that the disease became evident in August and with the warmer weather conditions did not spread to neighbouring plants.

The bacteria causing diseases of stock can be divided into two groups. One comprises *Bact. campestre* (Pammel) E. F. Smith and bacteria closely related to it as recorded by von Faber (13) in 1907, Cooley (12) in 1932, Kendrick (17) in 1938 and by Wilson (30) in New South Wales in 1938. The organism described in this work belongs, however, to a second group of green fluorescent bacteria.

Briosi and Pavarino (4) in 1912 first reported a green fluorescent organism causing a disease of stocks in Italy and named it *B. matthiolae*. They described the symptoms and the morbid anatomy of the attacked plants, but no critical account of the organism was given. Rudorf and Job (24) in 1932 observed a similar disease and on the basis of external symptoms and histological studies concluded it to be caused by *B. matthiolae*. Adam and Pugsley (1) in Victoria in 1934 recorded the occurrence of a disease of stocks due to a green fluorescent bacterium but thought it distinct from the one reported in Italy. In 1937 a disease of stocks was observed on the Italian Riviera (23) reported to be caused by *Bact. matthiolae*. Burkholder (8) suggested that *B. matthiolae* is identical with *Phytomonas syringae*, as inoculations of stock plants with the latter organism produced symptoms similar to these described by Briosi and Pavarino and by Adam and Pugsley.

Observing that no detailed account of the organisms described by the above-mentioned writers was supplied, it seemed advisable to make a study of the disease brought under notice.

Symptoms.

The diseased stocks observed in the field in the earlier or milder stage of the attack showed light green spots on the leaves. At a later stage the leaves became discoloured, pale green, with

scattered dark green spots and an uneven surface presenting a puckered appearance. Badly affected plants were dwarfed, the leaves small and deformed with incurled margins, the flowers discoloured and under-developed. In some instances it was noticed that the stems became woody and new lateral shoots sprang up which were stunted, carried deformed leaves and flowered poorly. Some stems showed dark brown streaks or splits and the cortex was discoloured To the naked eye the roots appeared normally developed

Isolation.

In the early stages of the disease the plants often yielded a pure culture of the pathogen, while badly infected plants usually showed invasion by secondary parasites. The infection being systemic, isolations were made from any part of the stem or leaves and pure cultures were used for inoculation tests.

Inoculation Studies.

To test the pathogenicity of the organism isolated, 24 hr. cultures on agar slopes emulsified with a few c c. of sterile water were used for inoculations A few sets of inoculation experiments were performed. In the first set in September, 1938, three horticultural varieties of stocks were used: Imperial, Ten Weeks and Nice The last named proved to be most susceptible to infection Seedlings were inoculated, the procedure adopted being to place them in moist chambers for 24 hours before and after the inoculation Out of six stock plants of Nice variety two were treated as control. Two inoculated by puncturing the stem developed local necrotic lesions, causing splitting of the cortex and stunting in growth. Two others were inoculated by pricking the leaves with a charged needle and one of them displayed within one week light green roundish spots about 2 mm. in diameter, followed by puckering of the leaves while the other showed only small brownish lesions around points of inoculation

Later inoculation tests were made with pure cultures re-isolated from the artificially infected stocks These tests were performed on plants of different ages and under varied conditions by puncturing the stem or leaves with a charged needle or by spraying. In most cases infection was obtained but the symptom picture was different, probably due to temperature and humidity changes, as no facilities for maintaining constant environmental conditions were available. Evidence pointed to the conclusion that young seedlings kept under lower temperatures were most badly affected. Sometimes only local brownish lesions were produced on stems and leaves, these later becoming puckered. In other cases irregular light green spots appeared on the leaves not only around points of inoculation but scattered irregularly. Dwarfing and deformation of leaves was produced most often by inoculating the stems of young seedlings Hand cut and

microtome sections of the infected stocks showed the presence of bacteria. Numerous re-isolations of the organism were carried out and the green fluorescent bacterium was identified by means of cultural and biochemical characters.

Morbid Anatomy

Plants which had been infected both naturally and experimentally were used for the purpose of obtaining material for hand-cut and microtome sections. Staining of the preserved tissues with Loeffler's methylene blue for 10-15 mins. and subsequent decolourisation with 0.5 per cent acetic acid gave satisfactory results. The bacteria were found in the parenchymatic cells and the vascular vessels, which were often blocked either by bacteria or a brown exudate. In advanced stages of the disease the tissues showed cavities filled with bacteria. The roots were less susceptible to invasion than the aerial parts of the plants.

Cross Inoculations.

Smith (28) considered the Italian stock disease caused by *B. matthiolae* to be similar to the Dutch disease of wallflower, of which no complete account was given. Burkholder (8) pointed out the similarity in the description of the stock organism and *P. syringae*. A survey of literature indicated the desirability of experimental inoculation of tobacco and tomato as some other members of the genus Phytomonas (Burkholder (6), (9)) are able to infect plants of the Solanaceae and Cruciferae families, producing leaf spots, e.g. *P. tabacum* (Wolf and Foster (16)) or *P. vesicatorum* var *raphani* (White (29)), resembling *P. campestre*. Also simultaneous biochemical studies proved the stock organism to be similar in its characters to *P. polycolor* (11), causing leaf spot on tobacco (Clara (10)) and to *P. marginale* (11), infecting lettuce (Brown (3)).

Cross inoculations with the organism re-isolated from the experimentally infected stocks were made to wallflower, lettuce, lemon fruit, tobacco and tomato plants. The method of cross-inoculation was similar to the one applied for infecting stocks. The results are given in *Table* 1.

Table 1

Type of Plant	Cross Inoculations.
Lemon fruit	No symptoms of infection.
Wallflower	Stem inoculations produced brown necrotic lesions, leaf punctures caused puckering and sometimes a slight deformity.
Lettuce and Tomato	Stem and leaf inoculations produced small brownish lesions around points of inoculation.
Tobacco	Stem inoculations caused slight necrotic lesions; around the leaf punctures lighter coloured zones were noticeable.

Attempts to re-isolate the stock organism from lemon fruit were unsuccessful. Isolations made 10 days after inoculations from the edge of lesions of wallflower, lettuce, tomato and tobacco plants resulted in obtaining cultures of the green fluorescent bacterium, identical with the one used for inoculations. No dwarfing or deformity of plants was observed at any later date. Isolations made from parts of the plants at some distance from the points of inoculation did not yield the bacterium.

These experiments indicated that the organism could survive in the cells of the host plants mentioned but was not able to produce systemic infection

The Causal Organism.

Pure Culture Studies

The technique adopted—unless otherwise stated—was in accordance with the methods recommended by the Manual of Methods for Pure Culture Study of Bacteria (Society of American Bacteriologists).

Morphology.

The morphology and size of the cells was obtained by observing smears treated by Benian's method with congo red. The cultures were grown on beef extract agar of pH 6.8 for 24 hours at 24°C. A colony on agar plate of the organism freshly isolated from stock consisted of cocco-bacilli of 0.75 x 1.0μ in size, or small rods with rounded ends whose length did not exceed 1.8μ. The bacteria occurred singly or in pairs. A smear from an agar slope culture showed rods with rounded ends, some straight, others slightly bent 0.75–1.1μ x 1.3–3μ in size. The cells were distributed singly or in pairs. Older laboratory cultures consisted usually of longer rods than the younger ones and often had chains 7μ to 35μ in length, in which the division into cells was not clear

Bacteria from a 24 hour old broth culture under dark ground illumination appeared as cylindrical rods, many paired together, some in short chains, displaying a swift darting movement across the field. Flagella were demonstrated by staining the smears from a 24 hour old agar culture by Cesares-Gil's method, using the mordant in 1:1 dilution and carbol fuchsin for 5 minutes. The flagella were polar, one or two in number. A few cells showed bi-polar flagella having one flagellum at each end of the cell or one at one end and two at the other; these cells might have been in the process of division as a slight constriction in the middle was noted. The flagella were wavy and longer than the cells.

The bacteria from a 24 hour old agar growth stained evenly using a simple stain, while in older cultures some cells stained deeper in contrast to other faintly stained ones. The organism proved to be Gram negative, not acid fast and non-sporing. No capsules were demonstrated by the methods of Hiss or Anthony.

CULTURAL CHARACTERS.

All cultures were incubated at 24°C.

Agar Colonies.—A 24 hour old agar plate of the freshly isolated organism displayed punctiform and circular colonies 1-2 mm. in diameter Some reached 4 mm after a few days of incubation. The colonies were smooth with an entire edge, raised and translucent, showing a brownish tint in transmitted light. The plates had an unpleasant odour A poured plate from a laboratory culture showed after two weeks of incubation circular colonies 6-7 mm in diameter with a greyish inner circle 5 mm in diameter, containing a thick point in the centre and a translucent and striated ring outside the circle Amongst the colonies some were found with a lobated edge, rather flat, translucent, often possessing an outer striated ring

Agar Stroke.—An abundant growth appeared after 24 hours of incubation, filiform with a slightly undulate margin, glistening, of butyrous consistency, producing a greenish colouring of the medium. After three days the green colouring became more distinct and the edge of the growth looked like a fine scalloped trimming Later the medium turned light brown Older laboratory cultures exhibited a less distinct green pigment which became more intense on rejuvenating the bacteria by passage through broth and through a few quick successive transfers to fresh agar slopes The freshly isolated cultures had an unpleasant odour which became less offensive with age

Agar Stab.—Growth occurred along the line of inoculation reaching the bottom of the tube.

Nutrient Broth.—Twenty-four hour old cultures showed strong turbidity. Clouds were raised on shaking No pellicle or sediment was visible After 48 hours the clouding became deeper, so that print could not be read through it At the surface of the cultures, at points of adhesion to the walls, a ring of granulated growth was noticed. In a few days a creamy sediment settled on the bottom of the tube while on the surface a very delicate pellicle was formed, easily detached by a slight disturbance. Often the surface displayed no pellicle, only a ring of granulated growth. A green fluorescent zone appeared at the upper part of the broth and gradually diffused into the medium

Gelatin Stab.—At 20°C in 24 hours the growth was best at the surface, the line of puncture being filiform with an initial drop of liquefaction, starting at top In four days the liquefaction became infundibuliform and spread to three-quarters of the medium. The liquefied area took on a green colouring, displaying a pellicle and a sediment In six days the gelatin was liquefied from wall to wall reaching almost to the bottom of the tube

Milk.—In 24 hours a ring of digestion appeared at the surface. In five days one-third of the medium was digested and became greenish. In eleven days half of the medium was watery,

greenish, and turned alkaline, while a soft creamy coagulate settled down. In twenty days the medium was cleared, greenish with a yellowish coagulate down the tube

Litmus Milk.—During the process of reduction of litmus many changes in colour took place, which were named according to Ridgway's classification. In the course of many observations it became evident though, that the occurrence of different shades was not constant, and in consequence a crude naming of the colours seemed most reasonable.

In 24 hours a slight ring of digestion appeared at the surface of the medium In 48 hours a lower ring of discolorization became visible In three days a soft coagulate started to form at the bottom of the tube In five days one-third of the medium was digested and yellowish in transmitted light. In eight days this yellowish colour had a green tint In twelve days the medium was digested and the reaction became alkaline In one month in transmitted light the yellow digested medium had a distinct green tint, in two months it became brownish-red. In three months it took on a beautiful wine colour, while in reflected light it looked dull blackish-green, and the coagulate a dirty greenish colour

Brom Cresol Purple Milk—In 24 hours a zone of digestion appeared on the surface of the culture and progressed toward the bottom of the tube taking on a purplish tint In eleven days the milk became distinctly purple in transmitted light; the medium was alkaline with a coagulate at the bottom of the tube.

Potato Medium.—An abundant moist light-brown growth was produced after 48 hours of incubation. The medium turned a darker shade

Uschinsky's Solution.—Good growth, sediment and a firm pellicle. The medium turned brilliant green, starting with a zone at the surface.

Fermi's Solution (Tanner's variant).—Growth at first was less vigorous than in Uschinsky's solution, with a firm pellicle and sediment Colouring was less distinct than in Uschinsky's medium

Cohn's Solution—No growth

Sullivan's Solution.—(Clara (10)) showed constantly green fluorescence

Physiological Characters

Relation to Free Oxygen.—This was determined by growing the organism in agar shake cultures and on agar slopes under anaerobic conditions, when a scanty film of growth was formed. The bacterium proved to be a facultative anaerobe.

Action on Nitrates.—A reduction of nitrates to nitrites without gas production was observed in 24 hours. In 48 hours a complete

consumption of nitrate beyond the nitrite stage took place and ammonia was liberated. Parallel control tests were conducted with sterile nitrate broth media and *Escherichia coli* cultures.

Production of Ammonia.—For this test Hensen's (15) method was adopted. Ammonia production was detected in peptone broth cultures of pH 7.6 incubated for three days. A sterile medium was tested and proved to be ammonia free.

Indole Production.—Two and seven days' old peptone cultures were tested by the Ehrlich-Böhme technique. No indole was detected. *Esch. coli* cultures were used as controls.

Hydrogen Sulphide Production.—The lead acetate strip technique was adopted. No hydrogen sulphide was detected. *Esch. coli* cultures were used for comparison.

Hydrolysis of Starch.—Starch broth media were used according to Eckford's method. After ten days a partial hydrolysis took place, indicating the production of erythrodextrin. After six weeks of incubation the digestion of starch did not progress further, and no sugar was detected at any time with Fehling's solution.

Cellulose digestion was tested as described by Clara (10). None was recorded.

Utilization of Amino-acid Media.—The formula of Frazier and Rupp (14) was followed by adding different amino-acids to a basic mineral solution. Good growth was recorded in peptone, asparagin, and aspartic acid, weaker in glutamic acid and tyrosin, showing the ability of the organism to derive its carbon and nitrogen requirements from the above-mentioned amino-acids.

CARBOHYDRATE REACTIONS

Two kinds of media were prepared. One set contained media with a peptone base and an addition of 1 per cent. of various carbohydrates, sterilized by steaming on three successive days. One per cent of Andrade's indicator was added and the reaction was adjusted to pH 6.8. These media were provided as additional means of quick identification by biochemical reactions of the organism isolated from infected or artificially inoculated plants. The results are given in Table 2.

TABLE 2.

Carbohydrate reactions (in peptone media)

Glucose.	Galactose.	Lactose	Sucrose	Maltose	Mannite.	Glycerin.	Salicin.
+	+	–	–	–	–	–	–

+ = acid. – = no acid, no gas.

Acid was recorded only in glucose and galactose after three days of incubation, while older laboratory cultures took a longer time to ferment these sugars.

The second set of media contained a peptone free base with an addition of various carbohydrates sugars, alcohols, glucosides or organic acids. These media were made up by following Burkholder's (8) directions To avoid any changes by heating of the media, all sugar solutions were passed through a Seitz filter. To record acid production brom cresol purple was used as an indicator, while phenol red was utilized to note any change to alkalinity in the organic acid media. The cultures of the stock organism used for inoculation of media were derived from the two morphologically different kinds of colonies found on agar plates, namely, the entire and the lobated edge types. Both of them gave identical biochemical reactions, recorded in the table below:—

TABLE 3

Carbohydrate reactions (in peptone free media).

(1) *Acid produced* in .—
Rhamnose, glucose, levulose, galactose, mannose, glycerol, mannite, acetic acid, citric acid, formic acid, lactic acid, malic acid, succinic acid.

(2) *Feeble acid* production in —
Maltose.

(3) *No acid, no gas* produced in —
Lactose, sucrose, raffinose, starch, salicin, tartaric acid

All fermented cultures displayed a distinct change of colour within six days of incubation, except rhamnose, which was more slowly fermented Maltose was discoloured after three weeks, indicating only feeble fermentation

TEMPERATURE RELATIONS.

Freshly inoculated agar and broth cultures were incubated at different temperatures and the influence on growth was noted.

TABLE 4.

Temperature Relations

Temperature °C	Growth	Colour of Medium
0	Fair	No change
10	Fair	Sometimes slightly green
20–24	Abundant	Distinctly green
30	Good	No change
37	Slight	"
38·5	Little or none	"
41	None	"

Motility was most active in 24-hour-old broth cultures incubated at temperature between 10°C.–30°C. After three days the bacteria became sluggish. A pellicle or a granulated zone was

formed at the surface of broth cultures at temperatures between 10°C.–30°C., not observed at 0°C. or 37°C. It is interesting to note that cultures kept for a week at 0°C. or 37°C. and then transferred to an incubator at 24°C. or transfers made from cultures kept at 0°C and 37°C. to media placed at 24°C. resulted in the production of an unusually brilliant green fluorescence.

Thermal Death Point.—This was determined by applying Magoon's capillary method Nineteen-hour-old broth cultures were used for the test 52°C. for ten minutes proved to be the thermal death point

Relation to Reaction (pH) of Medium—One loopful of a 24-hour broth culture was transferred to extract-beef broth media of different pH values, starting from pH 4 0 and reaching pH 10 0 On the acid side pH 4 4 proved to be the limit for growth, and pH 9 5 on the alkaline side These limits of growth are in agreement with the ones estimated by Berridge (2) At these pH values the broth tubes showed only slight turbidity after 48 hours of incubation. Most distinct fluorescence of the medium took place at pH about 7.4 and seemed to be more pronounced on the alkaline side, still showing a diffused green colouring at pH 9 1. On the acid side pH 5.4 represented the limit line for the production of green fluorescence, and only a greenish zone was formed at the surface

Effect of Desiccation—This was determined by placing drops of 24-hour-old broth cultures on sterile coverslips and letting them dry (Smith (26)). No growth appeared after seven days of desiccation.

Effect of Direct Sunlight—This was determined by following the method described by Smith (27) The test was carried out in the beginning of March about noon. Growth was obtained after an exposure of fifteen minutes, while no growth was recorded after an exposure of 30 minutes.

Vitality in Culture Media.—The organism was still alive in agar, milk, and gelatin cultures eight months' old, left at room temperatures. Eleven months' old agar and potato cultures were dry, and the bacteria proved to be dead

Conclusions.

The described organism is considered to be identical with the one reported by Briosi and Pavarino (4), and named by them *Bacterium matthiolae* The symptoms of plant infection, the inoculation tests, and the biochemical reactions of the organism prove it to be different to the one recorded by Adam and Pugsley (1) and not identical with *Phytomonas syringae* (8).

The organism belongs to the genus *Phytomonas* (6), so the proper name is *Phytomonas matthiolae*. A comparison with the green fluorescent bacteria listed by Clara (10) would include the

organism in the sub-group II. of the non-sucrose fermenters composed of soil saprophytes and weak plant parasites. This statement finds confirmation in the inability of the bacterium to attack all strains of stocks, and in the fact of the disease being checked easily by less suitable weather conditions.

The cultural and physiological characters of *P. matthiolae* show an affinity to *Pseudomonas fluorescens* (Flügge) Migula and to *P. aeruginosa* (Schröter) Migula (which is a synonym to *B. pyocyaneus* (Gossard)). Ruzicka in 1898 (25) considered *B. fluorescens* and *B. pyocyaneus* closely related, the difference in characters being due to the adaptation of *B pyocyaneus* to a parasitic existence and of *B. fluorescens* to a saprophytic mode of living. Niederkorn (21) in 1900 stated that amongst the fluorescent bacteria only two constant forms are to be found, namely, *B. pyocyaneus* and *B. fluorescens*. With the advance of scientific work much data was collected indicating the close relationship of the green fluorescent bacteria (Burkholder (6), (9); Clara (10), (11); Lacey (18), (19)). It is interesting to note here that one of the non-sucrose fermenters *P. marginale* (Brown) was considered by Metha and Berridge (20) to be identical with *B pyocyaneus*. In the light of recent research (22) thrown on the subject members of the *Phytomonas* group causing leaf-spot diseases are considered to be physiological adaptations of *Pseudomonas fluorescens*.

Short Description of *Phytomonas matthiolae*.

Small Gram −ve rod, occurring singly or in pairs, chains sometimes formed Size 0 75 − 1 1μ × 1-3μ. No spores, no capsules. Agar colonies with entire or lobated edge. Growth on agar slope and in broth abundant, producing green fluorescence. Fragile pellicle in broth. Gelatin liquefied. Milk alkalinized, coagulate formed, litmus reduced. Growth with green fluorescence in Uschinsky's, Fermi's and Sullivan's solutions, none in Cohn's. Facultative anaerobe. Production of ammonia +ve, indol −ve, hydrogen sulphide −ve, cellulose digestion −ve, starch feebly hydrolyzed Amongst peptone carbohydrate media glucose and galactose are fermented without gas production, while lactose, sucrose, maltose, mannite, glycerin and salicin are not fermented. Amongst peptone-free carbohydrate media rhamnose, glucose, levulose, galactose, mannose, glycerol and mannite also acetic, citric, formic, lactic, malic and succinic acid are fermented without gas production. No acid or gas is recorded in lactose, sucrose, raffinose, starch, salicin and tartaric acid. Maltose is feebly fermented Optimum temperature 20-24°C., minimum below 0°C., maximum slightly above 38 5°C. Thermal death point 52°C. for 10 minutes. Limits of growth in broth are pH 4.4 to pH 9 5. Best fluorescence at optimum temperature at about pH 7.4. The limit for desiccation is 7 days, for direct sunlight exposure 30 mins.

Summary.

An investigation was conducted on a disease of stocks which was reported in Victoria in 1938. The disease was proved to be caused by *Phytomonas matthiolae* originally recorded by Briosi and Pavarino in Italy, but not observed hitherto in Australia. Artificial infections were successful with healthy stocks of Nice

var., and cross inoculations were attempted. A pure culture study with full details was conducted and data on morphological, cultural, and physiological characters of the organism were secured.

Acknowledgments.

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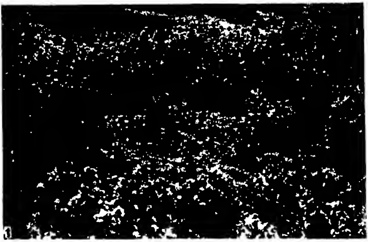

[Page 203.]

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Explanation of Plate.

PLATE VI.

FIG 1—A patch of diseased stocks with the healthy plants in the background

FIG 2—Left Healthy Control
Right Stock infected artificially by stem inoculation

[Photos—M Rothberg]

[PROC. ROY SOC VICTORIA, 53 (N.S.), PT 1, 1941.]

Art. VI.—The Granites of the Terricks Range and Lake Boga, in Northern Victoria

By EDWIN SHERBON HILLS, Ph.D., D.Sc.

[Read 11th July, 1940, issued separately 1st February, 1941]

Introduction.

In the district between Mitiamo, Terrick-Terrick, Pyramid Hill, and Mt Hope in County Gunbower, groups of low granitic hills rise above the almost featureless alluvial plains of the Northern District The Terricks Range, which extends northwards from Mitiamo and terminates north-east of the outstanding landmark formed by the conical peak of Pyramid Hill, constitutes the main granitic terrane, but outlying hills such as Mt Hope extend the area in which granites occur to over 60 sq miles. The most southerly outcrop, at Mitiamo, is nearly 40 miles distant from the northern boundary of the Central Highlands (see Physiographic Map of Victoria in Hills, 1940), and as no exposure of the country rock that was invaded by the granites has been observed, direct evidence of their age is not available

The boundaries of the granites were mapped by the Geological Survey during the preparation of the 1908 edition of the geological map of the State, and the map accompanying this paper (fig 1) reproduces the data from the original survey in more detail Major Mitchell, who ascended Mt Hope and Pyramid Hill in 1836, gives sketches of both these hills, and states that the rock is granite (Mitchell, 1835, Vol II., pp 155-9) Brief remarks on the physiography of the district, illustrated by aerial photos, have already been published by the present author (Hills, 1940, see Index), but no account of the petrology of the granites has previously appeared

The granitic outcrop at Lake Boga in County Tatchera occupies a small area (of the order of 1 sq mile) about 7 miles south of Swan Hill It is 50 miles distant from the northern boundary of the Central Highlands, 45 miles from the isolated granite knoll at Wycheproof, and about the same distance from Pyramid Hill The location of the occurrence is incorrectly shown on the 1908 geological map (8 miles to 1 inch), but has been correctly represented on maps of north-western Victoria previously published by the author (Hills, 1939, fig. 1; 1940, fig. 321, p. 243). I am indebted to Mr W Baragwanath for the use of MS maps of the Terricks Range and Lake Boga, on which my published maps and field work have been based, and also to Mr. G. Baker for heavy mineral analyses of the rocks whose Index Numbers are given below.

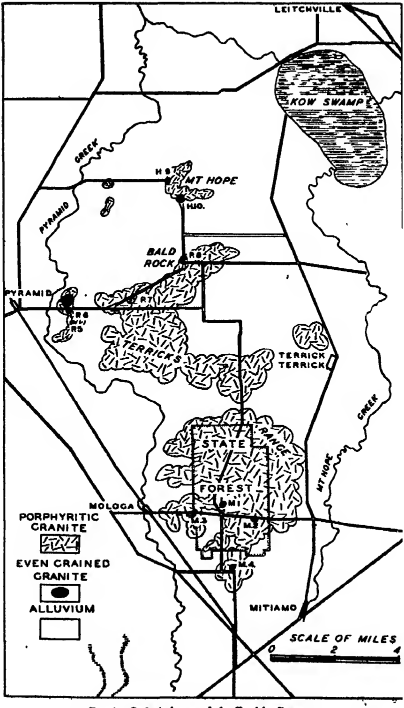

Fig. 1.—Geological map of the Terricks Range.

[Page 207.]

The Granites of the Terricks Range.

FIELD OCCURRENCE.

The granites of the Terricks Range and neighbouring districts outcrop as tors and bare rock faces at and near the summits of knolls that rise abruptly from marginal alluvial fans, these emerging gradually into the surrounding alluvial plains (fig. 2) Fresh specimens of the granite are only rarely obtainable from natural exposures, for the rock is generally weathered to a considerable depth, in such a way that, though it may remain intact, boulders will shatter under the hammer This results from loss of cohesion between the mineral grains owing to insolation, followed by the deep penetration of weathering agents along minute cracks

FIG 2—Pyramid Hill, from the north Note the abrupt change from the rocky hill sides to the smooth contours of the surrounding alluvial fans

All the granites in this district, with the exception of that of which Pyramid Hill is composed, are of porphyritic habit, containing large white phenocrysts of micro-perthite averaging about 1½ inches in length, also smaller phenocrysts of quartz, felspar, biotite, and subordinate muscovite, with a minor amount of granular, leucocratic, interstitial base The Pyramid Hill granite is, however, even-grained, consisting of cream or white micro-perthite, quartz, biotite, and abundant muscovite

At many localities the perthite phenocrysts show a definite parallelism, with their long axes orientated east-west (fig 3), but this regular arrangement is not found in all parts. The proportion of phenocrysts to groundmass also shows considerable variation, some patches of a few square yards being non-porphyritic, other small patches crowded with phenocrysts, as in the new quarry at the foot of Pyramid Hill At Mitiamo (Loc. M 2)—see map for localities mentioned—also at the new Pyramid Hill quarry (Loc P 6) and nearby at Loc P.7, biotite-rich schlieren of undulating habit occur, associated with patches of granite crowded with perthite phenocrysts, some of which project into the schlieren, in a manner resembling that described by Baker (1936) at the You Yangs Xenoliths are rare in most parts of the district, but a few were obtained from Mitiamo (Loc. M 3), also from Pyramid Hill at Locs P.6 and P.7. The xenoliths are fine-grained biotite-rich types, some of which contain porphyroblasts of felspar.

Aplites, quartz porphyries, pegmatites, and graphic granites occur as narrow dykes or veins in many parts, but all these

differentiates are very subordinate in volume to the granites. The dykes and veins typically follow joint planes, especially the nearly vertical east-west joints, with which the flow lines revealed by the micro-perthite phenocrysts are parallel. Approximately vertical north-south joints and flat-lying joints are also well developed, the latter often determining the occurrence of extensive bare rock faces, or pediments on which tors rest.

Owing to the absence of other hard rocks in the disrict, the granites are of considerable economic importance as a source of broken stone for road construction, concrete, and other purposes. Quarries have been opened at Pyramid Hill, but the readily-worked superficial quartzo-felspathic rubble and rotten rock developed by weathering are also extensively used on the roads

Petrology.

1. Porphyritic (Giant) Granite.

Micro-perthite phenocrysts as large as 2¾ in by 2 in. by 1 in were observed, but the average length is about 1½ inches. The crystals are tabular parallel to the clinopinacoid, other commonly developed faces being the unit prism, basal pinacoid and hemiorthodome $(\bar{2}01)$ Interpenetration Carlsbad twinning is almost universal. Orientation: *c* axis usually east-west; (010) approximately parallel to the flat-lying joints (fig. 3).

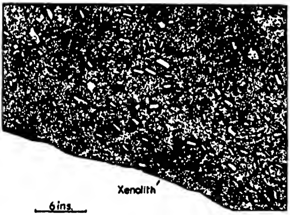

Fig 3 — Sketch of a vertical face of granite at Mitiamo, showing the alignment of felspar phenocrysts parallel with the flat lying joint that terminates the face below

Inclusions are common in the larger perthite phenocrysts. These include sub-rectangular oligoclase crystals showing composition zoning, usually with a sharply-defined outer acid coating or "jacket" (Ab. 85), and a more basic core (Ab. 70). Biotite

and quartz are also included in the perthites, especially in the outer parts of large phenocrysts. Typically, the included minerals are arranged in zones, evidently having been incorporated at certain stages during the growth of the perthite phenocrysts. Many of the latter exhibit composition zoning, and the composition zones are parallel to the lines of inclusions. This zoning is shown by variations in the distribution of fine ex-solution lamellae, as in the potash-felspars described by Trefethen (1937) and Spencer (1938), and is of an oscillatory nature

The majority of perthites exhibit both the "vein" type of perthite lamellae, and the very fine ex-solution lamellae or threads. The arrangement of the "vein" and ex-solution lamellae is different, as is well shown in slide [5690]. (Note: Numbers in brackets refer to slides registered in the Geology Department, University of Melbourne.) This is cut parallel to (010), and shows the two individuals of an interpenetration Carlsbad twin. The "vein" perthite lamellae are parallel to the vertical axis *c*, but the ex-solution lamellae make acute angles with *c*, the largest deviation (11 deg.) agreeing with the angle of the negative hemiorthodome ($\bar{6}01$). There appears to be no sharp demarcation between the "vein" and ex-solution lamellae (fig. 4E), which grade into each other, especially at the terminations of the "veins".

Slide [5694] illustrates a commonly occurring phenomenon. Along the borders of each "vein" perthite lamella, the host felspar is raised in double refraction to .007, it extinguishes at 9° on the (010) plane, and shows indistinct cross-hatching. In many other examples, as is illustrated by [5711], this apparently triclinic modification is also exhibited, and the cross-hatching is well-developed The felspar cannot be anorthoclase because of its high double refraction and extinction angle, and it is clearly close to true microcline. This reconstitution of the host K-falspar may be due either to the diffusion into it of Na and Ca from the "vein" perthite lamellae, or to a rearrangement of the monoclinic orthoclase lattice, induced by the adjacent oligoclase-albite of the perthitic "veins." Spencer (1938, p. 107) has recorded a similar effect in mircocline, in which the coarseness of the cross-hatch twinning is regulated by the adjacent "vein" perthite.

Slide [5694] is also interesting because there is a change in the nature of the perthite lamellae in the core of the crystal. The "veins" in the outer layers are polysynthetically twinned oligoclase (Ab. 85), but in the core these grade into untwinned bands of lower double refraction (but still higher than the host), which are monoclinic (fig. 4A, B) In the centre of the core the felspar is "shadow" perthite, of mottled appearance under high magnification. Inclusions of quartz follow the boundary of the core, along which there is also a narrow zone of microcline-like felspar resembling that marginal to the "vein" perthite lamellae.

Slide [5693] is a small perthite phenocryst from Loc. M.1. In preparing the slide, the (010) face was polished without removing much of the felspar, and thus the section shows the nature of the outer coating of the crystal. The major portion is soda-orthoclase, with X $\wedge$ (001), 9°, but the margin consists of two distinct zones, an inner composed of coalesced prismatic crystals in which the extinction angle on the trace of the (001) cleavage is 0°, and an outer of soda-orthoclase in optical continuity with the core. The inner of the two zones grades rapidly by means of composition-zoning into the soda-orthoclase on either side without any definite line of demarcation, and has a distinctly higher double refraction and refractive index. The optical properties therefore suggest that the inner of the two border zones is oligoclase In its anhedral form, the phenocryst differs from true Rapakiwi, but similar oligoclase margins to potash felspar have been recorded from many localities. The present example is unusual, however, in that the oligoclase is followed by a final orthoclase zone. Apart from the microcline fringing "vein" perthite stringers in orthoclase, this mineral is rare in the district. A few crystals showing uniform cross-hatching occur in slides [5708] and [5719]

Plagioclase in the porphyritic granites is typically oligoclase, ranging in composition from Ab. 70 to Ab. 85. The mineral invariably shows composition zoning, frequently with a marked discontinuity between the core and the outer zones ("jacketed" felspar), the latter also frequently containing myrmekite pustules. The plagioclase in the "vein" perthite lamellae averages about Ab. 85 in composition.

Quartz is hypidiomorphic to anhedral, and is present in large amount in all the rocks examined. It is included in the perthite phenocrysts, often along definite growth zones. These inclusions in slide [5693] are unusually large.

Biotite is pleochroic from X pale yellow or yellow-brown to Y, Z dark brown The crystals frequently show dactylitic terminations against felspars (both orthoclase and oligoclase), and contain many minute inclusions of zircon and apatite, around which pleochroic haloes are developed. It is rarely altered to chlorite, and shows various stages of bleaching, tending towards colourless hydromica

Muscovite occurs as well-developed plates, and also as stringers replacing orthoclase or microcline. In places it is intergrown in a lamellar arrangement with biotite. The freedom of this muscovite from inclusions of rutile or sphene distinguishes it from bleached biotite. In the Pyramid Hill Quarry, muscovite-quartz replacements of perthite are especially notable [5719].

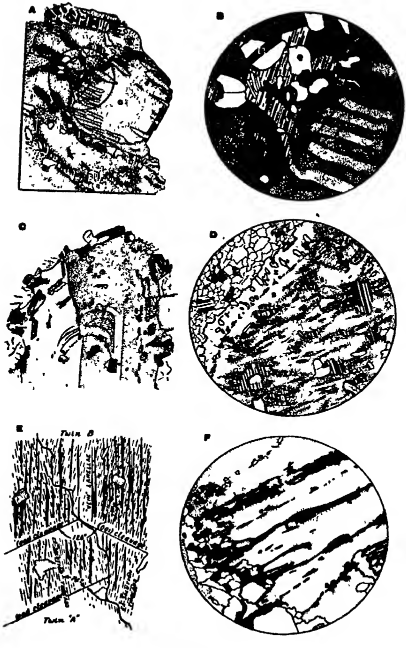

Fig. 4.

FIG. 4.—Types of Micro Perthitic Structures —

A—Portion of a perthite phenocryst from the porphyritic granite, Old Quarry, Pyramid Hill [5694] X12 Showing the core *C*, without perthitic lamellae in the centre, but with untwinned lamellae around the margins, these grading into twinned plagioclase (Ab 85) in the surrounding potash-felspar

B.—Enlargement of the portion within the circle in A. X36 In both A and B, note the change in the nature of the host felspar along the twinned perthitic lamellae, as shown by the close stippling *q*, quartz, *b*, biotite.

C—Perthite phenocryst in porphyritic granite, Mitiamo, Loc. M4, [5708] X4 Showing composition zoning, and the arrangement of included crystals of quartz, plagioclase, and biotite along growth surfaces, parallel to the composition zones. Note also the tendency for the groundmass crystals, marginal to the phenocryst, to align themselves with long axes parallel to the surface of the perthite phenocryst Only half the phenocryst is represented in the sketch

D—Portion of a perthite in the porphyritic granite, Lake Boga Quarry [5727] X6 Shows a marginal zone *z* containing quartz crystals elongated normal to the potash-felspar crystal face. Beneath this a line of inclusions *l*, of quartz and oligoclase, and beneath this again the body of the phenocryst, which is itself bordered with a zone *b* free from perthite lamellae. Note the change in the nature of the host-felspar along the plagioclase inclusions, as shown by the close stippling.

E.—Perthite phenocryst, Mt. Hope [5690] Diagrammatic sketch showing the geometrical arrangement of "vein" and ex-solution perthitic inclusions in two halves of a twinned crystal. Section parallel to (010), *c* axis vertical

F—Edge of an orthoclase crystal in pegmatitic patch, Old Quarry, Pyramid Hill [5721] X20. Shows replacement of potash-felspar (stippled) by albite (black). Quartz, unshaded

Accessory minerals present in the granites include apatite, zircon, garnet, ilmenite, and pyrite. The Index Number of porphyritic granite from Pyramid Hill Quarry is 5.61, and from Mt. Hope, 6.25

2 EVEN-GRAINED GRANITE.

Pyramid Hill itself is composed of an even-grained granite which contains abundant muscovite in addition to biotite. A similar type occurs in the old quarry south of the Hill. The granite consists of orthoclase micro-perthite, rare microcline micro-perthite, abundant oligoclase ranging from Ab. 70 to Ab. 85, with biotite and muscovite in sub-equal amounts Muscovite-quartz associations replace potash-felspar in part. Quartz is abundant, the grains showing sutured interlocking boundaries. Small andalusite prisms are enclosed in the larger muscovite plates [5717, 5718]. Accessory minerals other than andalusite are apatite and zircon. The Index Number is 4.47.

3 ACID DIFFERENTIATES.

Graphic granite (Loc. H10, slide [5725]) consists of orthoclase-perthite, the intergrown plagioclase consisting of Ab 70 (oligoclase-andesine). A little muscovite is also present.

Pegmatite occurs as veins and central "combs" in aplite dykes. At Pyramid Hill Quarry, pegmatite veins contain small groups of radiating tourmaline prisms, and consist of orthoclase perthite, oligoclase, muscovite, and quartz [5721].

Aplite dykes are common in both the porphyritic and even-grained granites. Slide [5714] from Mitiamo (Loc. M.3) illustrates the true aplitic types, consisting of quartz, abundant orthoclase-perthite and microcline-perthite, oligoclase (Ab. 80–Ab. 90), very abundant large myrmekite pustules, muscovite, both replacing potash-felspar and as large primary plates, and rare brown or bleached biotite.

Slide [5709] from Mitiamo (Loc. M1) is a rock which in hand specimen appears to be a true aplite, consisting of a fine-grained saccharoidal mass of quartz, felspar, and muscovite. Under the microscope it is seen to contain oligoclase (Ab. 75–Ab. 80), sub-equal to subordinate amounts of orthoclase micro-perthite, rare microcline micro-perthite and abundant quartz and muscovite. The amount of oligoclase present is unusually large, but all the aplitic types sectioned contain larger amounts of this mineral than is usual in granite aplites.

Slide [5715] is an aplitic type that intrudes the even-grained granite of Pyramid Hill. It contains orthoclase-perthite, subordinate oligoclase, a little biotite in large and small flakes, some bleached biotite, muscovite, and andalusite. Coarse patches a few square centimetres across consist of quartz, large muscovite plates, and andalusite.

Porphyry Dykes A fine-grained dyke at Loc P8 (slide [5726]) contains small phenocrysts of quartz felspar and biotite averaging about ½ cm across Zoned ('jacketed") oligoclase (Ab 70–Ab 85) is the dominant felspar and orthoclase-perthite is subordinate The other constituents are quartz biotite (some bleached) and subordinate muscovite The rock is a quartz porphyrite

A similar porphyry dyke at Mitiamo (Loc M1 slide [5713]) contains more orthoclase perthite, together with some microcline-perthite though oligoclase is present in sub equal amounts to potash-felspar Biotite and muscovite are both present, the latter both replacing potash felspar and in large primary crystals This dyke is also a quartz porphyrite

The largest dyke observed is at Mitiamo Loc (M3, slide [5695]) It is about 10 feet wide strikes at 35°, and is crowded with quartz and felspar phenocrysts averaging about 5 mm in diameter In places the felspars are subordinate and the rock consists of quartz phenocrysts with very little groundmass The felspars are all completely altered to fine grained aggregates of limonite stained sericite, and their original nature is not determinable The groundmass consists of quartz, sericitised felspars, and partially or completely bleached biotite The rock is a sericitised quartz porphyry It carries narrow quartz veins that have been prospected for gold

4 Melanocratic Schlieren

The biotite rich schlieren at Loc P8 slide [5706] and at Pyramid Hill Quarry slide [5720], contain large plates of biotite, many being joined together at their ends, where they interdigitate without leaving interstices Large stout apatite prisms up to 0 5 mm long are associated with the biotite The other constituents are orthoclase micro perthite, oligoclase (Ab 70), quartz, and subordinate muscovite Myrmekite is developed in the oligo clase jackets, accessory minerals include apatite in stout prisms up to 0 5 mm long also a little apatite in the form of small needles, and zircon

Slide [5704] from Loc P7, is fine-grained but contains a few porphyroblasts of biotite quartz and felspar It shows no banding Biotite occurs in the manner characteristic of reconstituted xenoliths as scattered crystals distributed evenly throughout the rock Many of the biotite flakes are smaller than in slide [5703] and some adjacent small flakes are in parallel orientation, enclosed within a quartz unit The quartz occurs as plates, full of inclusions of other minerals, the different parts of which are in optical continuity, as described by Brammall (1932) in xenoliths from the Dartmoor granite In some of these quartz units the included plagioclase and biotite show a radial arrangement, tending towards spherulitic texture The boundaries

of the quartz plates in places assume a regular geometrical arrangement simulating micrographic intergrowths. One biotite porphyroblast exhibits a large central homogeneous crystal surrounded by a solid mass of irregularly arranged decussate biotite flakes (Baker, 1936, p. 139) The felspar porphyroblasts are oligoclase (Ab. 75–Ab 85), and the cores of some of the smaller plagioclase crystals are andesine, with jackets of oligoclase grading to (Ab. 85). No potash felspar is present. Apatite occurs as rare stout prisms associated with large biotite clots, and also as numerous needle-shaped inclusions in quartz and plagioclase.

Slide [5705] from Loc. P8 is mineralogically similar to [5704], but the texture of the rock is different. The quartz hosts in which inclusions occur are more compact, containing a smaller proportion of included grains The felspars are larger, and are also poikilitic They consist of andesine (Ab. 65) jacketed with oligoclase ranging up to Ab. 85. Potash felspar is absent. (Note· The perthite on the edge of this slide is part of the adjacent granite) The other constituents are a little muscovite, apatite in the form of long needles (rarely stout prisms), and zircon

Slide [5707], from Pyramid Hill Quarry, is also similar in a general way to [5704], but the quartz poikiliths assume a pseudo-micrographic arrangement, with regular geometrical boundaries to the sieve-like crystals Quartz intergrowths with oligoclase also assume a form resembling coarse myrmekite, as described by Brammall (1932) Biotite develops as plates or fringing aggregates surrounding ilmenite grains, and is specially poikilitic, containing numerous inclusions of quartz in optical continuity among themselves The felspar is oligoclase-andesine, no potash-felspar being present Large apatite prisms, up to 0 5 mm long, as well as numerous thin apatite needles, occur.

The Lake Boga Granite.

In the Lake Boga Quarry, which is the only locality where the local granite may be studied in the field, jointing is well developed. One set strikes at 100° and dips at 85° to the north. The complementary approximately vertical joints strike at 190°, and flat-lying joints are also present All the joints are mineralised, narrow pegmatite selvedges containing black tourmaline crystals up to 8 inches long being developed along them. The granite itself is very heterogeneous. The average is a giant granite porphyry containing phenocrysts of microperthite of a flesh-pink to greenish tinge and about 1½ inch long, together with phenocrysts of muscovite, biotite, and quartz, the largest of these being about ½ inch across. These crystals are set in a finer-grained granular base composed of the same minerals. Leucocratic patches up to 3 or 4 feet long are free from the large perthite, quartz and mica phenocrysts, but contain patches, veins, and vughs

of tourmaline pegmatite, consisting of quartz, perthite, muscovite, and black tourmaline. The distribution of phenocrysts also varies within the giant granite, lenticular patches being crowded with phenocrysts, while others are even-grained. The latter are darker than the pegmatite-bearing leucocratic varieties On one face of a few square yards, the giant granite contains numerous xenolith-like blebs up to 6 inches across with hazy borders, and numerous phenocrysts of quartz and felspar Granite has also been obtained from the Lake Boga Prospecting Company's Bore, at a depth of 200 feet This is a coarse-textured grey rock containing a considerable amount of biotite, together with quartz and micro-perthite crystals, the latter ranging up to over half an inch in diameter The available specimens are not large enough to afford an adequate sample of the granite

THE PORPHYRITIC GRANITE

This contains large micro-perthite phenocrysts, individual crystals consisting both of monoclinic orthoclase hosts, and triclinic hosts with incipient cross-hatching, developed, as above described, along "vein" perthite lamellae. The latter consist of acid oligoclase (Ab 80–Ab. 85) Along one edge of the large phenocryst in slide [5727] there is a zone of orthoclase free from "vein" perthite lamellae. This zone is followed by a narrow band along which minute quartz and acid oligoclase crystals are included, and this in turn by an outer zone of orthoclase free from "veins," but including small quartz crystals, most of which are elongated along the *c* axis and lie at right angles to the orthoclase boundary. In the interior parts of the perthite, the "vein" lamellae are arranged in a zonal way, the outlines of the zones being parallel to the crystal boundaries, and evidently related to growth stages. Oligoclase (Ab 70–Ab 80), quartz, muscovite, and yellow to red-brown biotite occur as phenocrysts, and the groundmass, which is fine grained, contains perthite, oligoclase, quartz, biotite (some bleached to colourless hydromica, in various stages) and muscovite. Muscovite and biotite are in places intergrown, and minor amounts of muscovite also replace potash felspar Heavy accessory minerals are rare, apart from tourmaline There is a little apatite and zircon

Slide 2043 (Geological Survey Collection) is essentially similar, but is interesting in that the outer acid jacket of oligoclase crystals (Ab. 85) included in perthite is optically and morphologically continuous with the plagioclase of the "vein" lamellae.

Grey Leucocratic lenticles with Pegmatite The leucocratic base in which the pegmatite vughs and veins are dispersed is a medium-grained, granitic-textured rock consisting of quartz, orthoclase, microcline (with indistinct cross-hatching), abundant plagioclase (andesine Ab. 65 to oligoclase Ab. 80), and muscovite. Biotite is absent, and the potash felspar is free from perthitic lemellae,

both of the "vein" and ex-solution types [5697, 5698]. The felspars are cloudy with alteration products, the potash felspar being more altered than the plagioclase. The chief alteration is kaolinisation, but there is also some development of opacity due to finely-divided limonite The latter may represent a weathering product of hematite introduced during deuteric alteration, and the kaolinisation is also most probably deuteric. The Index Number is 6 25, being identical with that of the Mt. Hope granite.

The pegmatites are not particularly coarse-grained, the crystals averaging about half an inch to one inch in size They consist of smoky quartz, muscovite, cream perthitic orthoclase grading to microcline, rare apatite crystals as large as the other constituents, and, in patches, black or translucent tourmaline up to 8 inches long

Pink Lenticular Patches These are distinguished from the giant granite by absence of perthite phenocrysts, and from the leucocratic grey lenticles by the absence of pegmatite vughs and veins, and by their colour. They are similar to the leucocratic patches in mineral content, except that they contain a large amount of colourless to pale brown and dark brown tourmaline, in the form of skeletal crystals. They also contain a little biotite intergrown with muscovite, and a few anhedral grains of apatite, up to 0.5 mm. across. The larger quartz grains show evidence of regrowth along their margins, and the felspars are again kaolinised and limonite-stained, the potash felspar, as in the leucocratic lenticles, being more strongly altered than the plagioclase [5694, 5700]. The Index Number is 10.14, being abnormally high owing to the presence of tourmaline in large amounts.

The dark xenolith-like patches a few inches across, which occur in the giant granite, are actually tourmaline-bearing clots, similar to the pink lenticular patches except that they contain much more tourmaline, and also carry phenocrysts of quartz, perthite, and plagioclase, like the giant granite.

The granite from the Lake Boga Prospecting Company's bore contains quartz, zoned oligoclase ranging from (Ab. 78 to Ab. 87), perthite, biotite, and muscovite. Slide 2182 (Geological Survey Collection) also contains a biotite-rich clot which is probably of xenolithic origin It is a biotite-muscovite granite.

Petrogenesis.

Notable features of the above-described rocks are:—(1) the occurrence of two-mica granites, (2) the occurrence of porphyritic granites, and (3) the presence of andalusite in granite and aplite at Pyramid Hill

The andalusite-bearing rocks are especially interesting in view of the great rarity of xenoliths or other evidences of contamination throughout the province, and have already been discussed by

the author in a previous communication (Hills 1938) The presence of apatite in pegmatites at the Lake Boga Quarry is also noteworthy although the amount present is insignificant from the point of view of economic potentialities

1 *Perthite* —Ex solution perthite and the coarser sub parallel or ramifying lamellae of the vein type appear to grade into each other in many of the slides examined but the vein lamellae are markedly coarser than the very fine ex solution threads It has been suggested by E Spencer (1938) that vein perthite is formed by the simultaneous crystallization of plagio clase and the potash felspar host The hypothesis relates specifically to the microcline micro perthites examined by Spencer but should presumably be applicable also to orthoclase micro perthites such as those in the suite here considered It would be expected on this hypothesis that the vein plagioclase in the interior of a large potash felspar crystal would be more calcic than that nearer the periphery and a more or less regular com position zoning of the veins might also be developed during crystallization Such a condition is certainly not typical of the micro perthites in the rocks here described although in one example (fig 4 A B [5694]) the veins in the core are untwinned and may be composed of a potash soda lime felspar rich in potash and soda while in the outer parts they are twinned oligoclase (Ab 85) This unusual arrangement is however also explicable as due to the unmixing of an original potash soda lime felspar which itself had a central core differing in composition from the outer layers

On the assumption that the plagioclase veins are actual injections into or replacements of shattered potash felspar one would have expected to find inclusions such as quartz and oligo clase traversed by the vein plagioclase in at least a few examples This does not occur Vein injection or replacement too would not be likely to give rise to the regular distribution of perthite lamellae throughout large crystals that is actually observed It is worthy of note too that many albitic replacements of potash felspars in pegmatites show no resemblance to typical perthitic lamellae (see fig 4 F also Derry 1931 Niggli 1929 figs 4 and 5) It is therefore suggested that both the vein ' and ex solution perthitic inclusions resulted from the unmixing of an original potash soda lime felspathic solid solution

2 *Late Magmatic Phases* —In both the Terricks Range and Lake Boga granites differentiation has yielded late magmatic fractions relatively rich in oligoclase such as the porphyries and aplites of the Terricks Range and the leucocratic patches in the Lake Boga granite The mineral constitution of these aplitic differentiates closely resembles that of the ground mass of the porphyritic granites The suggestion is therefore that the final magmatic fluid remaining after almost complete solidification of

the potash-felspar-rich granites was relatively enriched in plagioclase (oligoclase). If these differentiates were expressed from the crystal mesh, they produced aplites. The inclusion of small oligoclase crystals along growth lines in the perthite phenocrysts, though not decisive, also suggests that at certain stages the crystallization of potash felspar was retarded, while acid plagioclase was concentrated within the sphere of influence of each perthite phenocryst, until the magma became saturated and oligoclase crystallized

The pegmatites, on the other hand, contain high-temperature potash felspars in large amount. They are of the type termed "simple pegmatites" by Schaller, in which no extensive replacement of original minerals has gone on, and their formation is readily explicable on the basis of the principles established by Niggli (1929, pp 2-5)

3 *Jointing*—All three joint sets in the porphyritic granites—the approximately vertical east-west and north-south joints, and the flat-lying joints—are locally filled with aplitic or pegmatitic veins, and are therefore primary

4. *Age Relationships.*—Field relationships indicate that the non-porphyritic granite at Pyramid Hill is intrusive into the porphyritic granite The profile of Pyramid Hill (see fig. 2, and Hills, 1940, figs 132, 329), suggests that the even-grained granite is a dyke-like mass, dipping easterly at about 45°, and striking east of north to west of south. It is probable, therefore, although the intervening area is marked by alluvium, that the outcrops at Pyramid Hill and the old quarry are connected along the strike of the dyke

5 *Petrographic Relationships*—The minor intrusions of granitic rocks that occur around the fringes of the Murray Basin Plains in north-western Victoria exhibit certain petrographic peculiarities that indicate the existence of a minor petrographic province in this region, perhaps distinct from the Devono-Carboniferous intrusions in the Central Highlands Thus at Mt Korong near Wedderburne, a porphyritic two-mica granite closely resembling that of the Terricks Range is intruded by a finer-grained non-porphyritic two-mica granite, as is also the case at Pyramid Hill (Mahony 1911). The Wycheproof granite, which occurs as an isolated low hill rising abruptly above alluvial plains, is a course-grained muscovite granite, and the Wooronook intrusion is a coarse-grained two-mica granite The Buckrabanyule Hills are composed mainly of a complex granodioritic mass showing evidence of considerable contamination, with strong developments of barren quartz veins, tourmaline-quartz veins, and pegmatitic patches The intrusion near Borung is also granodiorite. It is fine grained, and has a very well-defined grain. Muscovite-bearing granites are rare in Victoria, as elsewhere, and

it is significant that of the few occurrences in the State, five—Lake Boga, the Terricks Range, Wycheproof, Wooronook, and Mt. Korong—should occur in a well-defined arcuate belt on the western and southern borders of the Wimmera. This suggests that the granites of north-western Victoria may belong to a petrographic province distinct from that of the well-known Devono-Carboniferous granitic rocks of the "dacite suite" in the Central and Eastern parts of the State.

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ART. VII.—*Note on a Collection of Fossils from Queenstown, Tasmania.*

By DOROTHY HILL, M.Sc., Ph.D., and A. B. EDWARDS, Ph.D., D.I.C.

[Read 11th July, 1940; issued separately 1st February, 1941.]

In a recently published outline of the geology of the Mount Lyell Mining Field, Tasmania (Edwards, 1939), the sediments of the Queen River Series, which forms the most westerly of the "four, more or less parallel, north-south trending tracts" of rocks in that district, were considered to be of Upper Silurian age. This conclusion was based upon the determination of fossils found at two localities, namely, (i) some poorly preserved brachiopod casts in what appeared to be an erratic block of the Queen River Series, in the bed of Linda Creek, at the road bridge a little upstream from its confluence with the King River; and (ii) some corals from the limestone in the old flux quarry on the west side of the Strahan road, west of the smelters. Mr. R. B. Withers, who examined the specimens, named a number of the fossils, and expressed the opinion that they indicated for the Queen River Series "an age comparable with the Yeringian Series of the Silurian in Victoria." He suggested, however, that the corals from the old flux quarry should be submitted to Dr. Dorothy Hill for more expert determination.

This was done, and Dr. Hill's identifications, which follow, are such as to place the Queen River Series in the Upper Ordovician or the Lower Silurian, rather than in the Upper Silurian. This change in determination and in age relation applies only to the fossils from the limestone quarry. As the sequel will show, there is every reason to believe that the determination of the brachiopod casts as Yeringian forms is correct.

SIGNIFICANCE OF THE DISCOVERY

The conglomerates of the West Coast Range are generally accepted as representing the base of the Silurian in Tasmania, and so long as the Queen River Series is regarded as younger than them, it is necessary to postulate that the West Coast Range Conglomerates were raised to their present position relative to the Queen River Series by a great fault of Palaeozoic age, and that the igneous rocks forming the porphyry-schist belt of the Mount Lyell field were intruded along this fault zone. On this view the western scarp of the West Coast Range is to be regarded as an exhumed fault-line scarp. This still holds even if the Queen River Series is regarded as Lower Silurian.

If, however, the Queen River Series is of Upper Ordovician age, it is no longer necessary to postulate such a fault, and the West Coast Range Conglomerates have not necessarily undergone elevation, although some faulting may have occurred along their margin. The West Coast Range, on this view, is simply a feature of differential erosion, resulting from the highly resistant nature of the conglomerates. The fact that beds containing fossils of Silurian age over-lie the West Coast Range Conglomerates at the north end of Lake Margaret, and that an erratic block containing casts of brachiopods of Upper Silurian age has been found in the Linda Valley, and is probably derived from beds now eroded, but once overlying the conglomerates, does not disturb this new interpretation. It is necessary, however, to revise one's conception of the factor controlling the intrusion of the Queen River Porphyries, and the Mount Lyell Schists derived from them. These must be regarded as having been intruded along an unconformity

It is unfortunate that, in the present state of stratigraphic knowledge, the precise age of these beds remains uncertain, so that no decision can be reached as to which of the conceptions outlined above is correct.

Description of the Fossils.

The preservation of all the fossils in this collection is poor, and one must remain uncertain of the finer structures; photographic figures of the thin sections used in the study are impossible. *Tetradium tasmaniense* Chapman, previously described from Zeehan, has been particularly affected: the interior has been entirely recrystallized into rhombohedral crystals of calcite, and Mr. E. V. Robinson has determined that the exterior has been replaced by or coated with gypsum and small amounts of associated calcium carbonate.

AGE OF THE FAUNA.

The fauna contains *Alveolites* sp., *Protarea* cf. *richmondensis* Foerste, *Acidolites* sp., and *Tetradium tasmaniense* Chapman. *Alveolites* ranges from the Middle Ordovician to the Upper Devonian. *Protarea* is known in America from the Trenton and Richmond formations, in Estland from E to F_2, in Sweden in the *Leptaena* limestone, and in Norway in 5a and 5b. *Acidolites* occurs in the *Leptaena* limestone and the F beds of the Baltic, and in the Valentian of Gotland. *Tetradium* is known from the Chazy to the Richmond in N. America, and from the Craighead limestone (Ordovician) in Scotland. This suggests that the age of the Queenstown limestone is probably Trenton or Richmond in the American succession, and F. 5, and *Leptaena* limestone in the various Baltic successions. The Richmond, all or parts of

F. 5, and the *Leptaena* limestone are placed by some in the Upper Ordovician and by others in the Valentian (Lower Silurian. For references see Jones and Hill, 1940, p. 185).

MADREPORARIA TABULATA.

Genus ALVEOLITES Lamarck.

Alveolites Lamarck, 1801, p. 375; for references, genolectotype, etc., see Lecompte, 1939, p. 17.

DIAGNOSIS.—Massive or branching Tabulata, with corallites essentially compressed, of sub-triangular, semi-lunar, reniform or sometimes sub-rectangular section, opening typically obliquely to the surface, with thin, complete tabulae and large mural pores.

REMARKS.—Probably *Paleoalveolites* Okulitch (1935, p. 64, geno-type *Tetradium carterense* Bassler) from the Carters limestone (= Black River, = ? Caradoc) is a synonym of this genus, which otherwise extends from the Lower Silurian to the Upper Devonian. Okulitch considered a columella to be present in his genotype, but later (1938, p. 96) placed a second species, without columella, in his genus.

ALVEOLITES SP.

(Plate VII., fig. 1.)

Favosites cf. *grandipora* Eth. fil, Withers *in* Edwards, 1939, p. 69, Queenstown.

MATERIAL.—One fragment from the old flux quarry, Queenstown.

DESCRIPTION.—The fragment shows two groups of corallites, one encrusting the other. The transverse section shows semi-lunar or reniform corallites, their average dimensions being 0.5 mm. in the longer diameter, and 0.25 in the shorter diameter; and the corallites run parallel for at least 15 mm., the length of the fragment. Mural pores are very numerous and rather large, and pierce any or all of the walls or angles of the corallites. Septal spines were not observed with certainty. Tabulae are present, but are distant, thin and concave.

REMARKS.—I know of no species with which this might be closely compared. Its corallites are smaller than those of *Paleoalveolites paquettensis* Okulitch (1938, p. 96) from the Black River formation (= Caradoc) of Canada, and it has very numerous mural pores.

MADREPORARIA HELIOLITIDA.

Genus PROTAREA Edwards and Haime.

Protarea Edwards and Haime, 1851, p. 146; Lindstrom, 1899, p. 109.
GENOLECTOTYPE (chosen Bassler, 1915, p. 1043).—*Porites? vetusta* Hall, 1847, p. 71, pl. xxv., figs. 5a, b; lower part of the Trenton limestone, near its junction with the Black River limestone,

DIAGNOSIS.—Lamellar or encrusting Heliolitida without reticulum, with tabularia in which the walls and the twelve septa consist of large trabeculae in contact, and with free trabeculae rising from the floor of the calices.

REMARKS.—According to Foerste (1909, p. 211) and Troedsson (1928, p. 116), the specimens used by Edwards and Haime when they founded *Protarea* on *Porites? vetusta* were not conspecific with the type specimen of *Porites? vetusta* Hall. Foerste described this type as consisting apparently of a succession of lamellae varying from 1 to 2 mm. in thickness, and more or less free from each other in places. There are usually about five corallites in a width of 5 mm., although sometimes the corallites are wider. The vertical tubules between the corallites are fairly distinct under a lens The calices are rather deep, and the septa scarcely reach half-way to the centre. Foerste, and Troedsson considered that the Baltic and Richmond specimens used by Edwards and Haime and by Lindstrom differed in having no reticulum (i e. no vertical tubules between the tabularia). For the Richmond forms without reticulum Foerste proposed the name *Protarea richmondensis*. Troedsson considered it probable that the true *vetusta*, thin sections of which have never been figured, was generically different from *P. richmondensis*, and suggested that it might belong to *Protrochiscolithus* Troedsson. Bassler however named *Porites? vetusta* Hall, and not *P. vetusta* of Edwards and Haime quite definitely as genotype of *Protarea*, by giving a bibliographic citation; and it therefore seems that if different generic names are to be used for *vetusta* and *richmondensis*, the new one should be applied to *richmondensis*. Failing figures of thin sections of Hall's holotype of *vetusta*, the genus is here retained with Edwards and Haime's interpretation, i e, without reticulum. It occurs in the Trenton and Richmond of North America, the *Leptaena* limestone of Sweden, in E, F_1 and F_2 in Estland, and in 5a and 5b in Norway.

PROTAREA RICHMONDENSIS Foerste.

Protarea richmondensis Foerste, 1909, p. 210, pl. iv., fig. 9 Richmond beds of Ohio and Indiana

DIAGNOSIS.—Encrusting *Protarea* with four corallites in 5 mm., and with the trabeculae in the bottoms of the calices arranged somewhat irregularly.

PROTAREA cf. RICHMONDENSIS Foerste.

(Plate VII., fig 2.)

Favosites cf. *Gothlandica* Lamarck; Withers in Edwards, 1939, p. 69, Queenstown.

REMARKS ON THE TASMANIAN SPECIMEN.—The Tasmanian specimen agrees very well with Foerste's description, except that there are only three calices in 5 mm. It cannot be ascertained however whether it is encrusting; it is certainly a thin expansion.

In Canada and the U.S.A. the species occurs in Richmond beds; Lindstrom figured as *P. vetusta* a specimen from the Wesenberg beds of Estland. The Tasmanian specimen from Queenstown has its calical surface replaced by gypsum, and part of this is swollen and distorted by subsequent decomposition of the gypsum.

Genus ACIDOLITES Lang, Smith and Thomas

Acidolites Lang, Smith and Thomas, 1940, p. 13, *nom. nov.* for Jones and Hill, 1940, p. 184.

Acantholithus was preoccupied by Stimpson, 1858, for a crustacean.

GENOTYPE.—*Heliolites asteriscus* Roemer, see Lindstrom, 1899, p. 113, pl. xi, figs. 31-35, glacial drift of Sadewitz.

DIAGNOSIS.—Heliolitida with tubular reticulum, thickened walls, and spines on the tabulae.

REMARKS.—The genus differs from *Heliolites* itself only in the thickening of the walls, which is only less extreme than that in *Coccoseris* Eichwald (1860, genotype *Lophoseris ungerni* Eichwald, Lindstrom, 1899, p. 107, pl. xii., figs. 3-7, F_1 of Baltic), and in the more general occurrence of trabeculae on the tabulae. It may be that *Acidolithus* is better regarded as a synonym of *Coccoseris* but failing re-examination of the types, it seems wise to use *Acidolithus* for the less thickened members, although both genera have the same range in time, viz. Upper Ordovician and Lower Silurian of Europe.

ACANTHOLITHUS sp.

(Plate VII, figs. 3*a*, *b*.)

Cyathophyllum sp. Withers in Edwards, 1939, p. 69, Queenstown.

MATERIAL.—One specimen from the old flux quarry, Queenstown.

DESCRIPTION.—The corallum is 7 mm. thick, entirely surrounding a more or less cylindrical stem of *Tetradium tasmaniense*. On the surface calices about 0.5 mm. wide are 1 to 2 mm. apart, the intervening reticulum appearing minutely and closely papillate. Twelve septa line the calices, which sometimes show axial projections also. In vertical section the reticulum shows trabeculae continuous vertically, as thick as the distance between them, about 0.01 mm., connected by thin sola, the sola between neighbouring trabeculae continuing the same line, so that the whole corallum shows a number of concentric lines; this concentric structure is emphasized by a recurrent colouration of the corallum. The sola are close but the tabuli of the tabularia are very distant and concave. The septa appear to consist of long, upcurved spines, those of each of the twelve vertical series are so close as to form vertical laminae in some of the tabularia. In one case trabeculae were observed based on the upper surface of a tabula. In another tabularium there was a suggestion of a columella.

REMARKS.—The trabeculae of the reticulum are probably united to form polygonal tubuli, but no such outlines could be clearly seen in transverse section. The species does not appear to be close to any of the species described by Lindstrom, differing in the smaller size of its calices and in the indistinctness of the outlines of the tubuli, as also in the thinner walls. It resembles very closely the figures given by Lambe (1899, pl. v. figs. 8, 8a) of a specimen from the Trenton (Upper Ordovician) of Ottawa, Ontario, which he referred to ***Protarea vetusta*** Hall. The age it indicates would be that of the genus, F_1 or F_2 and Lower Valentian of the Baltic, i.e Upper Ordovician or Lower Silurian

GENUS INCERTAE SEDIS

Genus TETRADIUM Safford

Tetradium Dana, 1846, p 701 *Nom nud*, as no species were named
Tetradium Safford, 1856, p 236

GENOTYPE (by designation) *Tetradium fibratum* Safford, 1856, p 237; Upper Ordovician of Tennessee, associated with *Favistella alveolata* (Goldfuss) and other Hudson River species

DIAGNOSIS —Colonies which are hemispherical, lamellar, branching, cateniform or in small bundles, consisting of long prismatic tubes, usually four-sided, a lamina projecting towards the axis from the middle line of each wall; when the laminae meet at the axis the original tube is divided into four. The walls are without pores, but the tubes may be divided transversely.

REMARKS.—Dana named no species when he proposed the genus, and so, according to Article 25b of the International Rules of Zoological Nomenclature, his genus is invalid; but he gave a good description, and said it was based on a specimen, whose number was not given, from an unknown locality, in Yale College, New Haven. Safford, the first to use the name with species, applied it to the same general group as Dana, and as he was the first author to use a recognisable genotype, the genus should be ascribed to him

The genus has usually been included with the corals, and indeed the vertical laminae have somewhat the appearance of the septa of corals Okulitch has reviewed the literature in which the genus has been placed in the Anthozoa, and has regarded them (1935, p. 72) as forming a separate Proto-anthozoan group, bridging the gap between the Tetracoralla and the Alcyonaria, which he later (1936, p. 378) called the Schizocoralla. The latest Canadian Geological Survey Memoir (202) on the Ordovician of Ontario and Quebec lists ***Tetradium*** as a Hydrozoan, and this may be right. I do not think the genus shows sufficient resemblances to the Anthozoa to justify placing it in that class. The laminae appear to be connected only with increase, in a similar way to the divisional laminae which grow out from the walls of the Rugose coral Stauria during increase; they do not appear to be

divisible into major and minor cycles like the septa in the Rugosa, nor into successive cycles as in the Hexacoralla; nor are they acanthine as in the Tabulata or the Heliolitida. The Tasmanian specimens are not sufficiently well preserved to throw any light on the microscopic structure of the genus

Bassler has listed the American species of the genus (1915, p 1264) and Chapman (1919, p 8) has given diagnoses. Okulitch (1935) has recently re-described them They are found in the north-east of the United States, and the east of Canada, in the Stones River (= Chazy), Black R., Trenton, and Richmond groups, i e, from the Llanvirn to the Ashgill, and possibly into the Lower Silurian Outside America the genus is recorded in the Ordovician Craighead limestone of Scotland, and our species was originally described from Zeehan in Tasmania

TETRADIUM TASMANIENSE Chapman

Tetradium tasmaniense Chapman, 1919, p. 8, pl ; Smelters-road, Zeehan Tasmania, in a compact, blue-black limestone, the Gordon River limestone. Upper Ordovician or Lower Silurian.

Favosites aff *Lamitaris* Rominger; Withers *in* Edwards, 1939, p 69, Queenstown

? *Campophyllum* sp Withers in Edwards, 1939, p. 69, Queenstown

TYPES are in the National Museum, Melbourne

DIAGNOSIS.—*Tetradium* with branches about 11 mm in diameter, but occasionally constricted, springing from an irregular base, with tubes four-sided, about 1.5 mm. in diameter, incompletely or completely quartered by vertical laminae springing from the middle of each wall, and with occasional thin tabulae.

REMARKS ON THE QUEENSTOWN SPECIMENS.—The branches are not regularly cylindrical, and vary in diameter from 7 mm. to 11 mm.; their entire surfaces consist of calical openings, about 3 in 4 mm., or 4 in 5 mm. The outline of the calices is frequently that of a four-petalled Tudor rose The laminae tend to be thicker near the walls, and between them the walls are curved in transverse section The course of the tubes in the branches is not known It appears from Chapman's description of the Zeehan specimens that he saw no surfaces of the branch, but only sections of the internal parts of the branch. But from the measurements of both our specimens, and from the transverse section he figures, I think they are the same species The Tasmanian species somewhat resembles *T. cellulosum* (Hall, 1847, p 39, pl. ix.) from the Birdseye Limestone of New York, as the latter also is digitate or ramulose. Hall states that its branches anastomose, however, and this condition is not known in the Tasmanian species. Further, from Okulitch's description (1935, p. 54) of *T. cellulosum*, it would appear that the tubes were always parallel to the axis of the branch, and could not have opened on the surface of the branch. But Hall's description seems to allow that they did so open. Okulitch's description may not have been

based on Hall's type specimens. Our species would appear to be a branching modification of the massive *T. fibratum* group, which occurs in the Black River, Trenton, and Richmond of North America. Its age may thus be Middle or Upper Ordovician, or Lower Silurian, if the Richmond be regarded as Lower Silurian rather than Upper Ordovician.

CEPHALOPODS.

Rhizophyllum sp. Withers *in* Edwards, 1939, p. 69, Queenstown.

These specimens, which are nautiloid cephalopods, are being investigated by Dr. F. W. Whitehouse

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Explanation to Plate.

PLATE VII.

All figures approximately × 1.8 diameters.

All specimens are from the old flux quarry, now disused, at the northern end of Queenstown on the western side of the Strahan road, before it climbs out of the valley of the Queen R., half a mile N. of the railway crossing. They were collected by Dr. A. B Edwards and are at present in the collection of the University of Queensland. The age of the limestone is Trenton or Richmond; i e, Upper Ordovician or, if the alternative view of the age of the Richmond be accepted, Lower Silurian.

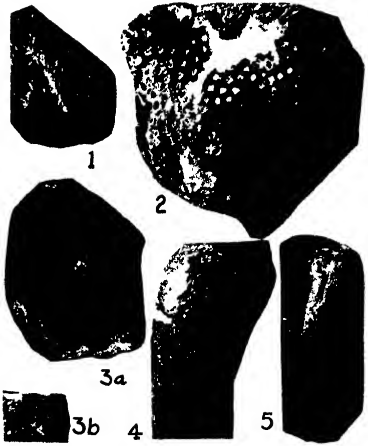
FIG. 1.—*Alveolites* sp. F.4287.

FIG. 2.—*Protarea* cf. *richmondensis* Foerste F 4288

FIG. 3—*Acidolites* sp. F 4289.

FIG. 4.—*Tetradium tasmaniense* Chapman F 4290.

FIG. 5.—T. *tasmaniense* F.4291.



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ART. VIII.—*The North-West Coast of Tasmania.*

By A. B. EDWARDS, Ph D., D.I C.

[Read 12th September, 1940, issued separately 26th July, 1941]

Introduction.

Although several short sections of the North-West Coast of Tasmania have been described briefly in various publications of the Geological Survey of Tasmania (Loftus Hills, 1913, Nye, 1934), and the geology of that part of it lying between West Head and Circular Head has been mapped in some detail (Stephens, 1908), no consecutive account of the coastal features has appeared.

The following notes are based upon observations made by the author during a recent visit to North-West Tasmania, when he had occasion to visit the coastline at a number of points between West Head and Marrawah, in connection with a field study of Tasmanian basaltic rocks. The cost of the field-work was defrayed by grants from the University of Melbourne and the Australian and New Zealand Association for the Advancement of Science

The North-West Coastline.

The north-west coastline of Tasmania is a compound one, and, from the evidence of raised strandlines and submerged valleys, its submergent and emergent features are due largely to the successive eustatic rises and falls of sea-level during the Glacial and Post-Glacial periods. During the periods of low sea-level the river valleys were deepened to below present sea-level, while during the periods of high sea-level estuarine conditions extended much further inland than at present, and gave rise to high level

flood plains, which are now preserved in the river valleys, as paired terraces No one stage of high or low sea-level was maintained sufficiently long to allow the coastline to mature, so that it is made up of youthful features of submergence combined with youthful features of emergence. East of Devonport features due to submergence tend to dominate, while west of Stanley those due to emergence are the more prominent.

The north-west coastline differs greatly in appearance from that of South-Eastern Tasmania, although the processes involved in their development were identical This difference is chiefly the result of their different geological structure. In the south-eastern part of the island there is a repeated alternation of narrow belts of relatively non-resistant Trias-Jura and Permo-Carboniferous sediments with narrow belts of highly resistant dolerites, often in the form of dyke-like masses which strike more or less at right angles to the coastline. As a result deep and narrow valleys have been eroded in the confined belts of softer rock, and the dolerite valley walls have tended to keep such streams from combining with one another. Submergence of this region has given rise to a number of long, narrow arms of the sea, separated by steep sided peninsulas that tail off into islands On account of their original depth, these drowned valleys were not readily silted up

In the north-west of Tasmania, on the other hand, the rocks offer a much more uniform resistance to erosion over wide areas. Only at widely separated intervals, where very resistant sediments were developed, as in the Asbestos Ranges, the Dial Ranges, and the Dip Ranges, has differential erosion been marked These ranges form prominent headlands and reaches of rocky coast In the wide intervening stretches of somewhat less resistant rocks, stream erosion developed wide valley systems, with a trunk river fed by numerous tributaries. Subsequently many of these wide valleys were filled by lava-flows, chiefly basaltic, and completely buried beneath a wide lava-plain Between West Head and Marrawah (fig. 1) the coastal features are of three general types, each of which is closely related to the geological structures of the region concerned For convenience these can be referred to as —

1. Silted Indentations with Prominent Cliffed Headlands.

This type of coastline occurs along the stretch of coast between West Head and Devonport; and between Jacob's Boat Harbour, Rocky Cape and Stanley It is made up of wide, deep bays, several miles across, which have been cut in belts of relatively resistant sediments (not covered with basalt) bordered by prominent cliffed headlands that have been cut in still more resistant rocks. Bay-mouth bars, and mid-bay bars, have closed off the heads of these bays, and led to their extensive silting up, so that the depths of the original indentations are masked in plans

which do not show the topography of the region. It seems possible that these bars may be as much due to emergence as to beach-drifting.

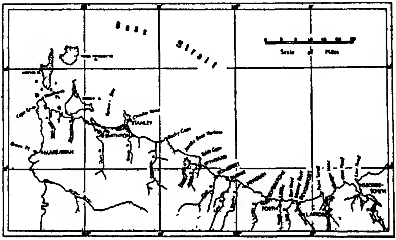


FIG 1.—Locality Map of the North West Coast of Tasmania.

2. THE SCARP COAST.

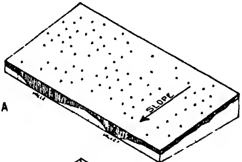
This extends from Devonport, through Ulverstone, Burnie, Wynyard and Table Cape, as far as Jacob's Boat Harbour; and also occurs in the immediate vicinity of Stanley Peninsula and Marrawah.

Its distinctive feature is the occurrence of a narrow emergent coastal plain, backed by a more or less continuous scarp that sometimes exceeds 200 feet in height. It owes its development to the undercutting by marine erosion of the sheet-like flows of basalt covering the Cambro-Ordovician and Permo-Carboniferous rocks which outcrop at present sea-level in these regions. The basalts in-filled the wide and gently sloping valley systems in these sediments, and formed a plain which rises slowly inland (fig. 2A). Marine erosion of this plain has produced a slowly heightening line of cliffs; and subsequent emergence of the old shore platform to the position of a coastal plain has removed the line of cliff from further attack by the sea, leaving it to weather into a steep escarpment (fig. 2B). Where the major rivers, like the Mersey, Leven and Forth come down to the sea, the coastal plain widens and the scarp shows a corresponding embayment.

The lava-flows in-filling the deeper parts of the old valleys frequently extended below present sea-level, and in a number of places still do. Where the width of lava-filled valley passing

below sea-level was not great, marine erosion cut away the valley walls, leaving the basalt-filled valley as a peninsula or narrow headland. Later, however, the encroaching shore platform reached the point where the bottom of the lava-filled valley passed above sea-level. Undercutting followed, and that portion of the lava-filled valley which passed below sea-level was left as an isolated outcrop of basalt on the shore platform (fig. 2B). Where the width of basalt was considerable it remained as an elongated, ridge-like island, such as Stanley Peninsula once was, where the volume of basalt was smaller it became worn down more or less to the level of the shore platform, although it frequently continued to protrude above the platform as rock stacks, like the Doctor's Rocks.

A



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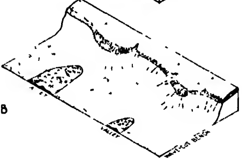

Fig 2.—Diagram illustrating the formation of the Scarp Coast A Basalt plain, before erosion, B After the formation of a shore platform and subsequent emergence

Where the width of the lava-filled valley or valleys passing below present sea-level was considerable, as between Table Cape and Jacob's Boat Harbour, or to a lesser degree at Don Heads, the resistant nature of the basalt appears to have restricted the width of such shore platforms as formed prior to the last emergence of the coastal region, and the present phase of marine erosion has removed all but a few traces of them. As a result,

along these stretches of the coast the scarp coincides with the present cliffs, which are 200 to 300 feet high. A narrow wave-cut bench has been formed at the base of the cliffs, and is kept free from debris by wave action, while the lower parts of the cliffs show almost vertical slopes (Pl. IX., fig. 3).

3. THE "EMERGENT" COAST.

This variety of coast extends from west of the Stanley Peninsula as far as Marrawah It is made up of a deeply indented coastline of the first type, fronted by a wide coastal plain of recent emergence, and extensive swamps Here and there in this plain are hills of resistant rocks which were previously islands, but have been "resumed" with the emergence of the coastal plain

I. SILTED INDENTATIONS WITH PROMINENT CLIFFED HEADLANDS.

Badger Head Bay The name Badger Head Bay is used here for the apparently nameless bay between the two prominent headlands of West Head and Badger Head, west of the mouth of the Tamar (fig 3) West Head is part of a ridge of columnar

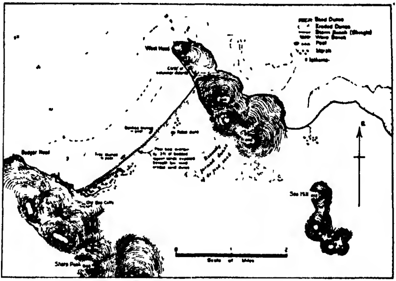

FIG 3.—Map of Badger Head Bay (adapted from Admiralty Chart No. 3649, Folio 98)

dolerite, which in places forms vertical cliffs over 100 feet high. Badger Head is composed of the overfolded Pre-Cambrian schists and quartzites of the Asbestos Range. Between these two headlands is a beach four miles long, backed by sand dunes. These are protected from north-easterly winds by West Head, but are

only partially protected from strong north-westerly winds by Badger Head. At the western end of the beach the dunes are 20 to 30 feet high, and tree covered. About one-third of the way along the beach, going eastwards, they become exposed to winds blowing past Badger Head, and in a distance of about 100 yards a transition takes place from stationary dunes to dune remnants (Pl VIII., fig. 6) which do not rise more than 3 to 4 feet above the level of the backshore. An occasional partially eroded high dune remains to show that these wind eroded dunes were once as high as those at the western end of the beach. The remaining dunes form ridges more or less parallel to the general wind direction. The sand from the eroded dunes has been blown inland for a distance of several miles, burying the lagoon that existed behind the old dunes, and also accumulating on the western slope of the dolerite ridge that forms West Head

A storm beach of coarse shingle has been built up to a height of 4 to 6 feet above the high tide level on the backshore, along its central and western part (Pl. VIII, fig. 4); and this protects the bases of the sand dunes from erosion by storm waves This storm beach has a steep slope to the sea, and a more gentle slope to the dunes, and the pebbles that compose it lie with their flat faces more or less parallel In places small impermanent lagoons are enclosed between this ridge and the sand dunes

Swampy conditions exist behind the dunes at the west end of the bay, and once extended the greater length of the bay, where a bed of peat two or more feet thick is exposed beneath a 3-ft thickness of bedded, iron-stained sand, in the foot of the low cliff, beneath the dune remnants. The iron-stained sands contain grains of buckshot gravel, and a thin layer of buckshot marks the contact of the bedded sand, deposited in the now-buried lagoon, and the sand of the dunes. This peat is also exposed below the storm beach (Pl VIII., fig. 3), while at low tide two patches of tree stumps and roots (chiefly *Banksia* (?)) set in peat, each covering an area of about 50 square yards, are exposed near the foot of the beach, about 80 to 100 yards from the cliff-face (Pl VIII, figs 1, 2, 5).

This indicates that the present recession of the dunes is part of a long continued process; and that previously there was, across Badger Head Bay, a bay-mouth bar which has now been driven in over the lagoon which it enclosed, to the position of a mid-bay bar. The old sea-cliffs, formed prior to the development of the bar, can be observed behind the present marshy lagoon near the western end of the bay.

Several streams run into the bay, and preserve their courses through the sand dunes, but only that one which drains the lagoon at the west end contains permanent water. Eastward drift of sand has deflected its mouth about 100 yards to the east, along the face of the sand dunes. The mouth is closed by a

bar; and when this bursts, the dunes on the outside curve of the "meander" caused by the deflection of the stream are energetically undercut and form steep cliffs The storm beach prevents the deflection of the mouths of the streams crossing the sand smothered area. These streams are dry, except after rain.

Port Sorell and the Rubicon Estuary. Port Sorell is at the mouth of the Rubicon and Franklin Estuary (fig 4), where these rivers empty into the wide bay to the west of Badger Head. The estuary is tidal for about eight miles upstream from this point. Point Sorell, the west headland of the bay, consists of Mesozoic dolerite. From Hawley to Point Sorell the surface of the dolerite forms a narrow, somewhat marshy, coastal plain, fronted by low sand dunes This tract, which is 20 to 30 feet

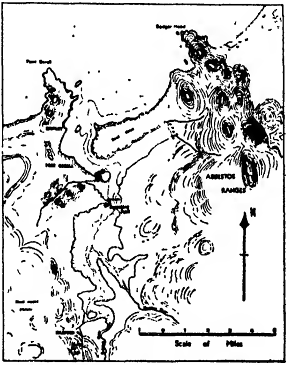

Fig. 4—Map of Port Sorrell and the Rubicon Estuary (adapted from Admiralty Chart No. 1079, Folio 98).

above the present beach level, appears to be part of an old shore platform. The dolerite extends beneath the mouth of the estuary, and outcrops as a reef on the east side of the channel, and as an island, tied at low tide to the west bank, on the western edge of the channel. The island rises 10 to 15 feet above high water level.

A curving mid-bay bar, five miles long, extends from Badger Head to the eastern limit of the dolerite The bar is about a mile wide, and is capped by sand dunes 30 to 40 feet high. Behind the bar extends an arm of the estuary, over three miles long, and from three-quarters of a mile to one mile wide, which provides some indication of the original depth of the bay. The growth of the bar has forced the estuary mouth over to the western side of the bay, where it has cut a channel through the dolerite, probably with the help of tidal scour

Half a mile upstream from the Port Sorell jetty, there is a small island, rising a few feet above high tide level, and tied to the west bank at low water The bed of the estuary here is composed of a light shingle of marine origin. The pebbles are of quartzite, and are apparently derived from the Asbestos Range. The island is built upon beds of this shingle that rise one to two feet above high water level. Presumably the shingle marks the position of a sea-beach formed before the mid-bay bar closed the bay It may be an old beach ridge, or the fact that it occurs above high water may indicate slight uplift

Two miles further upstream, at Squeaking Point, similar shingle is found, forming a flat bank about 10 feet above high water. Here, presumably, we have evidence of an emergence of this order The shingle continues upstream for some distance Going inland from Squeaking Point (westwards) a terrace 25 to 30 feet above the estuary level is encountered in a distance of about 100 yards The upper surface of this terrace is sandy, and somewhat uneven. It continues inland until near Burges Creek, where there is a change to hilly country

Five miles further upstream, where the State Highway from Devonport to Exeter crosses the Rubicon River, near Harford, the river, which is still tidal, has cut down to a depth of about 30 feet through an old flood plain which forms well marked high-level flats on either side of the estuary, and also on an island in midstream—left where a tributary joins the Rubicon a short distance downstream from the road bridge This old flood plain appears to be contiguous with the higher terrace at Squeaking Point. Upstream from the Harford Bridge the river is incising a meander in the raised flood plain This terracing may be taken as evidence of a repeated emergence of the coastal region of the orders of 10 and 30 feet

Rocky Cape West of Jacob's Boat Harbour the coast is formed of a belt of Pre-Cambrian quartzites, about seven miles wide These rocks are highly resistant, and stand in relief as the Dip Ranges. Prior to the basalt extrusions these ranges formed a much more prominent divide than they do now, and they are still conspicuous Along the seven miles of coastline to Rocky Cape the cliffs rise steeply from the water's edge, except

near the mouth of Sisters Creek, where there is a belt of low sand dunes and quartz gravels, fronted by beach. A small island, Sisters Island, occurs off the coast at this point.

Rocky Cape itself is formed of particularly hard white quartzites which are strongly bedded and dip at about 45 degrees to the north. Prominent vertical joints cut across the bedding. In profile Rocky Cape consists of a series of blocks showing dip slopes to the north and steep scarp to the south (Pl IX, fig. 2). Stephens (1908) considers that the scarps are due to faulting, but they may have developed from erosion of strongly jointed zones.

Two sea-caves at heights of 50 to 60 feet above sea-level occur at Rocky Cape. These caves, which have been described by Stephens (1908) are cut in cliffs of white quartzite The strong bedding planes and intersecting vertical joints have defined the shape of the caves The northernmost cave (Pl IX., fig. 1) occurs in a cliff about 160 feet high. The cave is about 40 feet high at the entrance and 15 feet wide It runs back into the cliff face for about 25 yards, the floor sloping gently upwards, and the roof coming down, while the cave narrows to about 3 feet wide It appears to be about 60 feet above present sea-level, but this is somewhat misleading, because the floor is covered with a midden-deposit that is more than 10 feet thick. The cave opens to the west, and its portal faces the remnant of an old shore platform Examination of this platform reveals sea-worn pebbles on its surface These are readily distinguished from the markedly angular hill-wash of this region

A second cave, facing towards Table Cape, occurs half a mile to the south of the first. It is of similar construction, except that the back of the cave is narrower, and the walls on either side are bedding plains dipping north. This cave is filled to a much greater depth with midden deposit in and about the entrance, so that it appears to stand 70 or 80 feet above sea-level, with a portal only 10 feet high On going into the back of the cave about 50 feet, however, one descends nearly 20 feet in the sloping cleft, even though the floor is still covered with midden deposit. It follows that the cave floor cannot be more than about 50 feet above sea-level, and that its dimensions are of the order of those of the more northerly cave Remnants of an old wave-cut bench at about the same level as the probable floor level of the cave form ridges that jut out for about 100 feet on either side of it, before descending abruptly to the sea. Cliffs, contiguous with the cliff in which the cave is cut, mark their landward terminations.

West of Rocky Cape there is a wide deep bay, whose further headland was formed by the ridges of Cambro-Ordovician sediments west of the Detention River. This bay has been silted up, with the formation of a marshy lagoon behind the sand dunes

of the bar. The dunes form a series of ridges varying in number from four to seven, parallel to the coastline. The ridges show gentle slopes to seaward, and steep slopes towards the marsh. Cliffs are being cut in the outermost dunes, exposing the roots of the trees along their crests, but there is no indication of a peat layer on the seaward side of the dunes, which appear to rest on a rock bench, and the fact that a patch of basalt, covered by a veneer of shingle occurs midway between the mouth of the Detention River and the road bridge, suggests that much of the marsh is underlain by a shore platform, at no great depth. Where the road bridge crosses the Detention River there is a depth of water of about 10 feet, due to the damming of the river by a sand-bar The water surface is still 15 to 20 feet below the level of the sand ridges on either side however.

From Detention River to Black River the coastal features consist of old cliffs fronted by narrow strips of raised shore platform, or marshes fronted by sand-dunes, and irregular wave-cut benches of Cambro-Ordovician sediments interspersed with stretches of sandy beach. Black River, which is tidal for some distance upstream, has cut down to a depth of about 30 feet below the level of the flat sandy plain behind the lagoons at its mouth This plain, which is 54 feet above sea-level at Black River railway station, appears to be a raised beach, elevated prior to the formation of the sand-bar which encloses the lagoons

II. The Scarp Coast.

Devenport to Jacob's Boat Harbour Between Point Sorell and Devonport a change in the nature of the coast is caused by the changed geology—the basalt plains which extend inland from the coast Near Devonport, at the western end of Pardoe's Beach, the coast consists of a narrow coastal plain, formed by the emergence of a shore platform, backed by a scarp that is capped by basalt lava-flows; and these features continue almost without a break as far as Jacob's Boat Harbour.

The width of the coastal plain varies somewhat, widening to a mile or more on either side of the mouths of rivers like the Mersey, Leven, Forth, Emu and Inglis, and narrowing to as little as a hundred yards, or even less, in the intervening stretches. The line of the scarp is, therefore, sinuous. Where the coastal plain widens it is usually fronted by lines of sand dunes and storm beaches of shingle, and behind these barriers lagoons (usually drained) have developed to various extents. Where the plain narrows, the line of sand dunes may or may not continue, but generally the rocks forming the present wave-cut bench are exposed, either as a continuous bench backed by low cliffs cut in the raised platform, or as a discontinuous wave-cut bench, forming a series of small headlands separating strips of sandy beach. Along much of this coastline the rocks in which the

waves are working are much-folded Cambro-Ordovician strata of varying hardness, and the wave-cut benches developed in these rocks are correspondingly irregular in shape and surface. Where, however, the bench is cut in softer Permo-Carboniferous sediments, as between Wynyard and Seabrook, the bench is a much more even surface, and only protrudes at low tide.

At the present cliff-line the coastal plain is 20 to 25 feet above sea-level It rises gently inland, and is about 40 to 50 feet above sea-level near the foot of the scarp, which marks the old cliff line. Frequently the actual height at the foot of the scarp is more than 50 feet above sea-level, as a result of accumulation of hill-wash material

Old rock stacks stand up above the general level of the plain at a number of points, as at Doctor's Rocks, and Woody Hill, between Burnie and Wynyard, and at Goat Island, near Ulverstone. Raised beaches of rounded boulders and coarse shingle form a veneer on the raised platform at the first two of these points, and a pebble beach is exposed at Sulphur Creek. More extensive raised beaches, which merge into flood plains, are found at the mouths of nearly all the rivers entering the sea along this stretch of coast; and most of the coastal townships are built upon these deposits.

Mersey River The banks of the Mersey at Devonport rise to a height of 20 to 40 feet above the high-water level of the estuary, and are built partly of beach deposits and partly of silt. Upstream, as noted by Twelvetrees (1911), the Mersey valley contains well developed terraces 20 to 30 feet above the present flood plain, and these extend from Devonport to beyond Latrobe, a distance of more than four miles Twelvetrees suggests that the region has been affected by repeated uplift because he observed traces of what he considered were still earlier flood plains in the Mersey valley

At the western end of Devonport township is the small promontory of Mersey Bluff, which at some time may have formed the western headland of a deep bay now occupied by the coastal plain and estuary of the Mersey. This promontory is composed of Mesozoic dolerite, and formed part of a ridge separating two parallel valleys, now marked by basalt flows which pass below sea-level on either side of the Bluff. The Bluff was an island during the high sea-level periods, and now presents the appearance of a small tied island, but the sand dunes on the western side of the tombolo may mask a connection with a raised shore platform that runs from west of the Bluff to the mouth of the Don River.

The basalt on the eastern side of the Bluff is largely covered by beds of shingle to a height of about 20 feet above high water mark (Stephens, 1908). That on the western side forms the eastern headland of the Don Estuary, where it is covered with

beach ridges of coarse basalt shingle. On the western side of the small estuary it forms the Don Heads, which is a line of cliffs, composed of more than one flow of basalt, marking the position of a deep, wide valley that passed well below present sea-level Along this stretch of the coast the coastal plain is lacking, and the scarp coincides with the cliff-line West of this basalt-filled valley the scarp recedes, and a narrow coastal plain develops again, and continues as far as Leith A smaller basalt-filled valley passes below sea-level at the eastern end of Lillico's Beach, but the basalt residual is no longer connected to the basalt on top of the scarp

Forth River Paired terraces, about 30 feet above the level of the present flood plain of the river, extend for a distance of about nine miles up the Forth River from the township of Forth, and just below the bridge at Paloona is what appears to be a remnant of a second set of terraces at about 80 to 100 feet above the present flood plains. Below Forth township the flood plains widen, but the 30 foot terraces continue for a considerable distance downstream, particularly on the western side of the river, where it merges into the coastal plain that continues as far as Ulverstone Between Forth and Leith, at the mouth of the estuary, there is a suggestion of a further terrace only a few feet above river level, but observations were not sufficient to confirm this. Leith, which is 40 feet above sea-level, is built on a coastal plain consisting of sand and shingle beds, grading at the coastline into storm beaches of shingle

The mouth of the Forth Estuary was once a wide, deep bay, but it has been silted up into a flood plain as a result of the development of a bay-mouth bar from its western margin. This bar consists of a series of beach ridges of shingle, now several feet above high tide level, and covered by sand dunes about 20 feet high on their seaward side

Leven River At Ulverstone (50 feet above sea-level) the coastal plain, on which the town is built, becomes over a mile wide, and the section of it exposed in the banks of the Leven where the Nietta railway bridge crosses the river, shows 20 to 30 feet of silts and gravels at high water. This coastal plain decreases in height towards the sea, where it is fronted by sand dunes, and is not more than 10 to 15 feet above sea-level at the coastline.

Blythe and Emu Rivers Between Ulverstone and Penguin the coastal plain is at first fronted by marshes (usually drained) formed behind the line of sand dunes that marks the cliff-line. Mid-way to Penguin, however, the Dial Ranges, which are composed of resistant Cambro-Ordovician sediments and formed a divide in the pre-basaltic landscape, come down to the coast, forming a high ridge almost at right angles to it. West of Penguin the Cambro-Ordovician sediments are capped by basalt,

but they outcrop again as a ridge more or less parallel to the coast from Blythe Head to Wivenhoe All along this stretch of the coast an irregular wave-cut bench marks the shore-face, and this bench is backed by a sharp cliff, 20 to 30 feet high, cut in the narrow raised shore platform which forms the coastal plain.

The Blythe River has cut down to a depth of about 25 feet near its mouth through a narrow plain composed of sands and gravels, and a similar flat, 30 feet above sea-level, occurs at Wivenhoe, the most easterly suburb of Burnie. Where the Emu River crosses this plain a section of bedded shingle and sand, 20 to 25 feet deep, is exposed

Burnie Township· At Burnie there appear to be two raised shore platforms Burnie Park (West Burnie) and much of the central part of the town is built on a short platform about 40 to 50 feet above sea-level, while Burnie Beach (from the piers to the Showground) is backed by a lower flat, about 15 feet above sea-level.

The Cam River. From West Burnie to Somerset the road runs along a narrow strip of coastal plain, which is fronted by low cliffs and a ragged wave-cut bench, formed in the folded and contorted Cambro-Ordovician sediments At Somerset the mouth of the Cam has cut down to a depth of about 25 feet through bedded gravels (Pl. VIII., fig 9), which form a terrace on either side of the river, and merge with the adjacent coastal plain The shape of the pebbles suggests that this deposit is probably a raised beach.

Wynyard Plain Between Somerset and Seabrook (22 feet above sea-level) the coastal plain widens to about a mile, and west of Seabrook the scarp develops a deep, wide indentation In this indentation lies the Wynyard Plain, which is 40 to 60 feet above sea-level. It extends from the right bank of the Inglis River, southwards for one and a half miles, and eastwards to the northern edge of Woody Hill The plain is composed of sands and clays, but east of Stinking Creek it changes to coarse shingle. Loftus Hills (1913) considers that the sands and clays represent a silted up estuary, or lagoon that formed behind the shingle beach. Where the Flowerdale and Inglis Rivers cross this plain, they have cut valleys to a depth of 30 to 40 feet below its surface, indicating an emergence of the land of this order since the formation of the plain.

The shore-face, in the vicinity of Wynyard, is cut in soft Permo-Carboniferous strata, which have been planed off to a more or less smooth platform, only exposed at low water.

Wynyard—Table Cape—Jacob's Boat Harbour: At Wynyard the coastline turns sharply to the north, as far as Table Cape, and then turns westwards again to Jacob's Boat Harbour. Table Cape is an uncovered laccolith of analcite-dolerite (trachydolerite,

Twelvetrees, 1908), which has formed a buttress against marine erosion. This laccolith was uncovered before the adjacent basalt lava-flows were extruded, and they, in turn, are older than the Wynyard Plain, or the bay which it infills.

Between Wynyard and Table Cape these lavas overlie Tertiary and Permo-Carboniferous sediments, but west of Table Cape they pass below sea-level, and for a distance of about five miles the wave-cut bench and cliffs are formed of basalt. The cliffs rise over 200 feet high along this stretch, and are nearly vertical in their lower parts (Pl. IX., fig. 3) Approaching Jacob's Boat Harbour, the western wall of the old valley rises above sea-level, although several minor valleys, each filled by basalt, are encountered at sea-level before the Boat Harbour is reached.

At the Boat Harbour itself remnants of two shore platforms are preserved (Pl. IX., fig. 4). The higher one forms cliffs 20 to 30 feet high at the back of the beach, and extends back as a narrow gently sloping platform to the old sea-cliffs of the scarp, where it is about 50 feet above sea-level. The lower platform forms the flat-topped promontory, 300 yards long, and 50 yards wide, that protects the cove from the north-west wind. It is 10 to 15 feet above sea-level, and is being undercut at several places.

A further remnant of the upper platform occurs about half-a-mile east of the Boat Harbour, where a bluff of white quartzite, forming the interfluve between two of the smaller basalt-filled valleys that pass below sea-level, contains a niche which appears to be the remnant of a cave, at about 50 to 60 feet above sea-level. The cave—if it is one—is filled with angular debris from rock falls.

Stanley Peninsula: Stanley Peninsula (fig. 5) is a composite-tied island The major part of the peninsula—the Green Hills—consists of a ridge of basalt (an old valley flow) tied to the mainland by a Y-tombolo, the lagoon of which has been drained (Pl. X., fig. 2). On either side of the tombolo, spits, which are about three miles long, have enclosed shallow arms of the sea. At low tide both inlets are dry except for central channels, which carry the drainage from streams flowing into them. A drain connects the inlets, and the workmen who dug the channel reported that the tombolo is underlain at a depth of a few feet by a bed of shells which is three feet thick. Excavations in other parts of the tombolo have confirmed this. In its narrowest part the tombolo is less than half-a-mile wide. Just within the mouth of the East Inlet a small spit has been built out in the reverse direction to the major spit

The basalt ridge fills an old valley which sloped to the north, and passed below sea-level in that direction. Originally the basalt was probably connected with the extensive flows, now fronted by a scarp, in the vicinity of Forrest. Where the tombolo is

situated, the valley floor, which was composed of soft Permo-Carboniferous (?) sediments, passed above sea-level. Marine erosion was able to undercut the basalt filling here, in the manner indicated in fig. 2, and so convert the northern part of the basalt flow into an island.

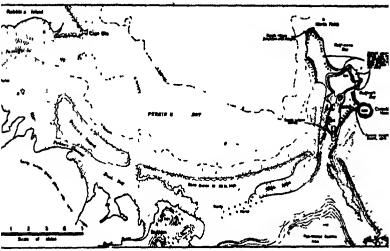

FIG 5.—Map of Stanley Peninsula and Perkin's Bay (adapted from Admiralty Chart No 3687, Folio 98)

On its western side the tombolo dies away about a mile north of its junction with the basalt ridge About fifteen distinct sand ridges, separated by swales 2 to 3 feet deep occur on this part of it.

On its eastern side the sand bar and the low dunes which cap it extend as far as the township of Stanley, which is built in the shelter of Circular Head, and form part of the Y-tombolo which ties that one-time island to the Green Hills (Pl. X, fig. 1). The lagoon enclosed by this tombolo was still a swamp in 1826, when the Van Diemen's Land Company became established at Circular Head, but has since been drained The shore platform beneath this tombolo is formed of a soft sandstone or mudstone, which outcrops at low tide at both ends of Godfrey's Beach, and also on the south-eastern side of Circular Head, between the old and the new wharves. The sand dunes backing Godfrey's Beach form a series of seven ridges, but this is largely due to the erection of brush fences, now buried, in an attempt to stem the landward advance of the sand Two small streams, rising in springs and seepage at the foot of Green Hills, are conveyed in drains through the lagoon, until they lose themselves in the dunes, and a well at the western end of Godfrey's Beach, at the foot of the basalt ridge, supplies an abundance of good water, and was previously used for the town supply.

Basalt Ridge: The ridge consists of flows of basalt and olivine-nephelinite filling an old valley. At its southern end, where it is highest (250 feet above sea-level) the ridge is narrow and uneven, rising into several small eminences. Further north it broadens out into a level plain about 150 feet above sea-level. At the northern end the basalt passes below sea-level.

At the western end of Godfrey's Beach a junction of basalt with bedrock is exposed at low tide. The basalt is vesicular near the contact, and does not stand out in relief from the sediments. At about 15 feet from the contact it becomes dense and columnar, the columns being inclined at right angles to the slope of the valley wall. Finely laminated cross-jointing, at right angles to the axes of the columns, then becomes prominent, and enables the shape of the valley walls and floor to be determined. This valley, and another which joined it from the north-east, appear to have been tributaries to the main valley, which lay a little further to the west.

Where Godfrey's Beach meets the basalt ridge there is a remnant of an elevated shore platform, running up from 25 feet above sea-level at the present cliff, to about 40 feet at the old sea-cliff behind it An exposure along the present cliff shows that this old bench is covered by a veneer of rounded boulders about 2 feet thick (Pl. VIII, fig 8). The boulders include occasional pebbles of quartzite and reef quartz in addition to basalt and analcite-dolerite (from Circular Head) Half-a-mile further along the cliff there is a more extensive raised shore platform, about 30 feet above the present wave-cut bench, and running back to a height of 40 to 50 feet above sea-level (Pl X, fig 3). This bench also has a veneer of rounded pebbles. Rock-stacks have been cut from it in one or two places, and islets and rocks some hundreds of yards out to sea testify to the further extension of this shore platform—and of the basalt-filled valley—further out to sea The present wave-cut bench is being formed in a layer of vesicular basalt, which has enabled the waves to undermine the more dense basalt in places, cutting small caves, a miniature arch, and, near the northern end of the raised platform, a small blow-hole.

Turning the point into Half-Moon Bay, still further traces of this raised shore platform can be observed (Pl VIII., fig. 7), until the southern edge of that part of the Peninsula known as the Western Plain is met. On the western side of the Green Hills, further indication of emergence is found. The western shore is fronted with a beach almost half a mile wide at low tide, and as a result there is little wave erosion, or cliff formation along this stretch of the coast. The back of the beach is marked by a few pebbles, and a line of miniature sand dunes, which enclose a lagoon about 20 yards wide. From this lagoon there is a sharp rise of the land of from 15 to 20 feet in a matter of

a few yards, and then a narrow sloping plain rising to about 50 feet above sea-level in about 100 yards. The slope then steepens to the steep side of the basalt ridge. This raised strip of plain, which runs along the whole western side of the Green Hills appears to be an old shore platform.

Western Plains. The Western Plains (Pl. X., fig. 4) form a low-lying north-westerly extension of the peninsula, about three miles long, and one mile wide. Where it joins on to the Green Hills it is faced by a scarp as marked as that along either side of the basalt ridge elsewhere. The surface of the plain is not wholly flat, and in its central part there are one or two gentle hills that rise to 70 to 80 feet above sea-level, and show an occasional outcrop of large angular boulders of basalt. Midway along the north-eastern shore, there is a cliff face, about 20 feet high, in which decomposed basalt is overlain by a veneer of rounded pebbles and boulders similar to those overlying the raised platform at the western end of Godfrey's Beach This veneer is about 3 feet thick, and contains occasional pebbles of quartzite. There can be little doubt, therefore, that this is an old raised shore-platform and pebble beach. The surface of the platform and beach rises inshore to a height of about 35 to 40 feet. The probability is, therefore, that the Western Plains are largely a raised shore platform cut in a basalt-filled valley which passed below present sea-level, and was a tributary to the main Green Hills valley.

Much of the Western Plains, however, is of secondary origin. All along the north-eastern, and along a considerable extent of the south-western shore, extensive beach ridges of pebbles and boulders of basalt have been built up to a height of 15 feet above sea-level (Pl. VIII., fig. 10) The successive ridges are occasionally as wide as 20 feet, and are separated by swales 2 to 3 feet deep. In the vicinity of North Point, a series of such ridges has been built up to a total width of about 200 yards Sand has accumulated to some extent behind these ridges, but the wind is too strong for dunes to form, except where the plain meets the Green Hills ridge. However, quite extensive marshes and lagoons have formed behind the pebble ridges, especially in the northern part of the plains. Kelp and seaweed act as the cementing medium to the pebbles. In places one can observe the old shore platform descending abruptly to these pebble beaches, almost as a cliff.

Circular Head (The Nut): Circular Head is the remains of a small steep-sided laccolith. It consists of gigantic columns of analcite olivine-dolerite, 4 to 6 feet in diameter, and rising to a height of 460 feet above sea-level. The columns are vertical, and in places form vertical cliffs several hundred feet high, with a fringe of steeply sloping scree around their lowest part (Pl. IX., fig. 1).

The top of the Circular Head is not as flat as appears from a distance, and two small valleys, which junction, form a hanging valley about 80 feet deep on the southern side, indicating that a valley ran in that direction prior to the erosion of the sedimentary walls of the laccolith.

Stanley is built on an old pebble beach, 30 to 40 feet above sea-level, at the foot of the Head. Limpets have been found associated with the pebbles (Nye, 1938, p. 8), and two such shells were secured from excavations in progress in the basement of the Post Office, in association with water worn pebbles This material may not have been *in situ*, however

Receding Spit and Siltation of Stanley Harbour The Eastern Spit is receding. Mr. Partridge, the editor of the *Circular Head Chronicle*, informed me that it has receded about half-a-mile during his fifteen years of residence at Stanley. This recession appears to have been in progress for a considerable period. Thus Stephens (1908, p 765) states that whereas the original track to Stanley followed the East Spit, and easily forded the bar across the mouth of the inlet at low tide, by 1908 (or earlier) the channel had deepened so that travellers had to strike inland after crossing the Black River, and follow the tombolo.

If the recession of the spit continues, it will leave the tombolo, which carries the road and railway, exposed to the action of storm waves at its narrowest part Efforts are being made to stem the recession by planting marram grass along it, but if, as seems probable, the recession is due to wave action rather than the wind, and is related to the stage which the coast line has reached in its development, these efforts will meet with little success.

The sand from this receding spit is being carried northwards, and is silting up Stanley Harbour, at the rate of about one inch a year, according to a report issued by the Marine Board, about 40 years ago This conforms with the fact that the ship *Caroline*, of 330 tons burden, which came to Stanley in 1828 (Hare, 1928) berthed at the inside part of the old wharf, where to-day a small yacht can barely find sufficient water at high tide, and where the sand is bare at low tide Since the *Caroline* would draw at least 8 feet of water, and would probably require a foot or two of water to spare, at least 96 inches of sand have been deposited in the last 100 years. Bathing boxes which were in use fifteen years ago are now so far removed from water deep enough to swim in, even at high tide, that they have been abandoned; and the place where it is reported that a 300-ton schooner was built and launched in the early days is now about 100 yards from the high tide mark

Godfrey's Beach, on the other hand, does not appear to be silting up, and the sand dunes are sometimes subject to attack by storm waves. Thus a storm during Easter, 1939, swept away

30 feet of dunes. Wind is constantly blowing the sand inshore; and the storms, according as they come from the north-west or the north-east, shift the sand from one end of the beach to the other. This trend has been active since 1837 (Gunn, 1854).

III. The Emergent Coastline.

Perkin's Bay· The sand bar which forms the three mile long spit on the west side of Stanley Peninsula (fig. 5) continues westwards in an unbroken curve as far as the mouth of the Duck River, a distance of eight miles. At its western end, as at the eastern, the bar forms a spit about three miles long, here enclosing the eastern arm of Duck Bay. On the other side of the narrow channel through which the Duck River discharges into Perkin's Bay, the sand bar forms again as the dune-covered Perkin's Island (wrongly shown on geological maps of Tasmania as composed of basalt), and continues in the same sweeping curve for another four and a half miles, as far as Robbins' Passage. Between the bar and the mainland is a channel from half-a-mile to a mile and a half wide, which is very shallow, being largely exposed sand at low tide; and for a distance of about three miles, between the east arm of Duck Bay and West Inlet, the channel has been converted into a sandy marsh, which joins the bar to the mainland. The excessive silting and sanding up of this stretch of the channel is probably due to the fact that this strip of the bar is most exposed to strong winds from the sea, whereas other parts of the bar are relatively sheltered by Stanley Peninsula and Robbins Island.

On the seaward side, soundings show that the sea-floor is very shallow, and has a very gentle slope. The presumption is, therefore, that this bar is an off-shore bar which has been joined to the mainland by silting of part of its lagoon. The breach in the bar at the mouth of the Duck River appears to be stationary, but the disposition of sand off the mouth suggests that a certain amount of westerly beach-drifting is in progress.

The origin of the bar is, no doubt, related to the features of recent emergence described in the next section.

Smithton to Woolnorth and Marrawah· Between Smithton (Duck River) and Woolnorth Point and Marrawah, the compound nature of the coast is prominent. In plan the coast has the outline of a relatively youthful coast of submergence (fig. 6). Drowned river mouths and off-shore islands of various sizes point to drowning of an extensive river system.

Siltation of the estuaries, followed by emergence, has given rise to an extensive coastal plain 20 to 25 feet above sea-level, which rises gently to 50 feet or more as it is followed inland. The plain extends inland for several miles in places, and merges into a series of five large swamps—Mowbray Swamp (two arms), Briton Swamp, Montague Swamp and Welcome Swamp, each of which is about 100 feet above sea-level where crossed by the

Smithton-Marrawah road These swamps are separated from one another by ridges rising 100 to 200 feet above the level of the swamps The most easterly of them, the Christmas Hills, is the most prominent, and is capped in places by basalt. The Welcome Swamp on its west side abuts against the basalt capped plateau (The South Downs) near Marrawah.

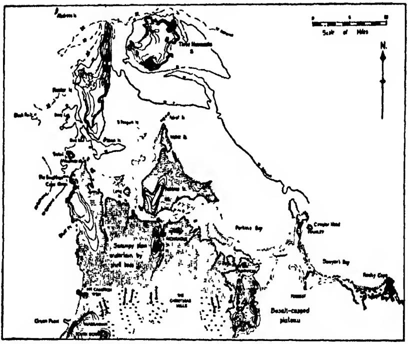

FIG 6.—Map of the Emergent Coast, west of Smithton (adapted from Admiralty Chart No. 3687, Folio 98)

The thickness of the sands forming the plain, and the shape of the underlying bedrock are unknown, but in places along the Duck River the sands are only 15 feet thick. Marine shells, regarded as Pleistocene, have been found at depths of 6 to 10 feet at various parts of the plain, near Smithton (Nye, 1934), and in the vicinity of the Welcome River, while freshwater shells and marsupial remains were found associated with peat during the draining of the eastern arm of Mowbray Swamp (Nye, 1934, pp. 59, 60 and refs.); so that while marine conditions dominated near the mouth of the original bay, they gave way to estuarine conditions towards the bay head. A similar gradation has been observed on the Deep Creek Plain, east of Smithton (Nye, 1934). These two contemporaneous plains are separated by a long ridge of resistant dolerite dyke and its adjacent sedimentary wall rocks (Pl. IX., fig. 7). The Deep Creek Plain

rises about 100 feet above sea-level, and this leads Nye (1934, p. 61) to suppose that the Duck River Plain also may have been higher originally, but may have undergone erosion since its emergence. The presence of old dune ridges on the Duck River Plain, and on the stretch of plain between Montague and Woolnorth Point, suggests, however, that the present surface is more or less the original one.

The Duck River flows in a meandering course across the plain, near Smithton, and has cut down its bed to a depth of 15 to 20 feet into the sands and underlying bedrock, but has not formed flood plains at the new level. Deep Creek, on the other hand, has formed a small flood plain, or marsh, below the level of the plain, at its mouth.

The level of the coastal plain is broken by isolated sand ridges trending more or less parallel to the coastline, and by occasional ridges of older rocks rising 200 to 400 feet above sea-level. These ridges of older rocks may be designated resumed islands since, prior to the emergence of the coastal plain they formed coastal islands similar to those in existence off the present coastline (fig. 6), and were restored to the mainland by the emergence rather than by any silting process Such resumed islands are represented by the basalt-capped hills on which the village of Montague is built; the basalt ridge at Montague West; the adjacent hills of Cambro-Ordovician sediments; the high land stretching southwards from Woolnorth Point to Bluff Point, and fronting the sea with the precipitous cliffs of Cape Grim; the small dome-shaped laccolith of Mt. Cameron West (Pl. X., fig. 5); and possibly the basalt-capped plateau of the South Downs at Marrawah Two similar resumed islands, formed of basalt ridges, occur on Robbins Island, surrounded by a similar emergent plain.

Woolnorth Point: Just west of Woolnorth Station are the remains of old rock stacks and sea-cliffs, cut in Cambro-Ordovician sediments, and fronted by indurated beach or dune sands, which form a narrow coastal plain 40 to 50 feet above sea-level. The present shore consists of an irregular wave-cut bench, cut in steeply dipping sediments, interspersed with pocket beaches. Close to Woolnorth Point a series of beach ridges of shingle about 80 yards wide have been built up to a height of 5 to 6 feet above high water mark (Pl. IX., fig. 8). The pebbles are chiefly of olivine-basalt, presumably derived from Robbins Island, or from some of the smaller islets off the coast, whose geological characters are not shown on geological maps. The ridges are 3 to 4 feet wide, and separated by swales 1 to 2 feet deep. The inner ridges tend to be grass-covered, and lead back to low cliffs cut in the raised shore platform.

The old sea-cliffs west of Woolnorth Station mark the northern end of the large resumed island that extends southwards as far as Studland Bay (fig. 6). Along its western side this island is

exposed to the south-west winds which bring frequent heavy storms against the shore. Marine erosion has destroyed all trace of the coastal plain on this side of the resumed island, and has cut steep cliffs, up to 200 feet high, in the higher land of the old island (Pl. IX., fig. 5). The cliffs are being undermined, with the formation of caves, and their rapid recession is attested to by the occurrence of the Doughboy Islets, off Cape Grim (Pl. IX., fig 6). These two islets were attached to the mainland at no distant date, but the sea has cut channels between them and the mainland

Trefoil Island, some distance to the north-west, has a similar cliffed coastline.

Marrawah. A beach four miles long stretches from Green Point, west of Marrawah township, northwards to Mount Cameron West, which is a small, steep-sided laccolith of analcite-olivine dolerite (Pl X, fig. 5). Sand dunes extend the length of the bay, rising as high as 60 feet in its central part. Behind the dunes are the extensive marshes of the coastal plain, which extends back to a steep scarp about 300 feet high. The scarp consists of old sediments capped by an unknown thickness of Miocene limestone, and about 100 feet of basalt. Remnants of an old shore-platform about 50 feet above sea-level can be observed in places at the foot of the scarp

Green Point appears to be a tied island, joined to the mainland by a Y-tombolo which encloses a small marshy lagoon, but there may be a rock connexion with the mainland beneath the sand dunes on the northern side of the tombolo. Green Point itself appears to be another remnant of the raised shore platforms found at the foot of the scarp.

At the southern end of the beach leading to Mt. Cameron West, the dunes are intact, but at the northern end they are subject to strong south-westerly winds, and the sand has been blown inland for a distance of over a mile. This has exposed beds of a Recent shelly limestone beneath the dunes. Exposure has been aided by wave erosion, which has cut a cliff in the dunes and limestone adjacent to Mount Cameron West.

The limestone consists of sand and comminuted shell fragments with occasional whole shells. Adjacent to Mt. Cameron West its top is 25 to 30 feet above sea-level, but a gentle southerly dip carries it below sea-level in about half a mile. The limestone is brownish coloured, compared with the white to earthy-white colour of the dunes, and the upper beds have been indurated with limonite and lime, the latter mostly in the form of tubular calcareous concretions. The indurated beds stand out in relief as the result of wind etching. Close to Mount Cameron West, where there is a rapid run-off for rain water, the limestone has been eroded into a small area of badlands. At this point the sandy cover has been stripped completely from it. The fossil content of these beds (recorded in the Appendix) proves that they are

of Quaternary age, so that their present position above sea-level indicates an emergence of the shore line in relatively recent time. Similar beds occur on the north side of Mt. Cameron West, and also at a distance of about two miles north of the Mount, at a similar elevation above sea-level (Meston, 1932).

North of Mt. Cameron West are further beaches, divided at intervals by reefs of rock (projecting wave-cut benches) and backed by sand dunes. The dunes are being blown inland into the swamps that extend for some miles behind them, and cuspate lagoons, or lakes, lie between the swamps and the inner fringes of sand.

Springs of fresh-water occur on the part of the beach exposed at low tide at two points between Green Point and Mt. Cameron West. At one place one spring was observed (close to the Marrawah picnic ground), while at the other seven springs formed a cluster. The drainage from the marsh behind the dunes apparently seeps through the sand along the surface of the buried shore-platform, and when the "head" becomes sufficient, issues as springs on the sea-side of the dunes, causing the sand to "boil" in small circular depressions which overflow to the sea. The largest pool measured 3 feet in diameter. The relation of these springs to the shore-platform suggests that the shore-platform continues for a considerable distance inland, as the floor of the marshes.

Towards the northern end of the beach, where wind action is stronger, the heavy seas have thrown up a storm beach of pebbles and boulders, and where these have filled the mouths of streams through the sand dunes, permanent waterways are maintained, for even when the pebble-filled stream mouths are covered over with sand, the water can easily percolate between the pebbles. As a result the streams at this end of the beach are not blocked by intermittent sand-bars as is found more usually along the Tasmanian coast.

The Raised Shorelines.

The observations given above indicate that remnants of at least two raised shorelines can be found at intervals along the north-west coast of Tasmania, one at 5 to 15 feet above sea level, and the other at 40 to 50 feet above it, thus confirming the observations of Lewis (1934, p. 82); and that a number of the rivers flowing into Bass Strait along this stretch of coast show a development of terraces in their valleys at corresponding heights above their present levels.

The 40 to 50 feet strandline is the more pronounced of the two, and can be traced from the Rubicon Estuary as far as Marrawah. The 5 to 15 feet strandline is more difficult to establish. In many places there are wide shingle beaches up to 10 feet, or even more, above sea-level. These beaches fall steeply to the water-line, and sometimes lagoons are impounded behind

them, but it is probable that many, if not all, of them have been formed by storm waves acting at present sea-level. Some doubt must also attach to wave-cut benches which project only a few feet above normal tide level. Such benches could be due to storm waves as easily as to emergence. At some localities, however, as at Jacob's Boat Harbour, there are undoubted remnants of the 15 feet strandline.

There is also a suggestion, in the form of doubtful river terrace remnants in the Mersey and Forth valleys, of the existence of a third strandline at about 100 feet above present sea-level, but this could not be confirmed.

The occurrence of raised beaches and shore platforms along the northern coast of Tasmania and the islands of Bass Strait was first recorded by Johnston (1888), who noted the occurrence of *Helicidae* sandstones at heights up to 100 feet above sea-level on Cape Barren Island, Badger Island, Chappell Island, Green Island and Kangaroo Island, in the Furneaux Group, and a raised beach about 100 feet above sea-level on Chappell Island. On Badger and Green Islands he recorded a series of shelly beaches invariably 40 to 50 feet above sea-level, and sometimes nearly a mile from the shore, while on Flinders Island he found a stratified bed of oyster shells in the banks of the Arthur River, about two miles above its mouth, and 30 feet above sea-level In addition he noted comparable features "on other places along the northern coast of Tasmania," as well as "subordinate valleys within main ones," and river terraces in the valleys of the chief rivers debouching into Bass Strait. Later workers have confirmed Johnston's observations. Twelvetrees (1908, p. 165) states that raised beaches "exist all along the northern coastline and in the Straits islands. Elevated beaches of marine shingle are seen at the mouths of the Blythe and Emu Rivers, and elsewhere along the shore of Bass Strait" Lewis and Nye (1928, p. 27) write that "the whole coast shows a recent uplift, and a very marked shore platform exists, particularly from Devonport to Stanley." David (1923) has recorded a raised beach 3 to 4 feet above high-water on the Tamar, near Launceston; and Lewis (1934) records raised beaches at 5-15 feet and 40 feet above sea-level in the vicinity of Burnie.

Submerged Shorelines.

Evidence points to the existence of at least one, and probably two, submerged shorelines. The submarine contours of the Tamar Valley can be traced on Admiralty Chart No. 3649, Folio 98, for a distance of 3 to 4 miles out to sea. The valley form can be followed to a depth of 15 fathoms, and with less certainty to the 20-fathom contour, indicating the existence of a submerged shoreline at a depth of about 120 feet below sea-level. Similarly, in the vicinity of Hunter Island and Three Hummocks Island. in the extreme north-west (fig. 6), the contours of submerged valleys can be traced on the Admiralty Chart, No. 3649, Folio 98.

to depths of 25 fathoms, but apparently do not continue to greater depths. Here, then, the submerged shoreline lies at about 150 feet below sea-level.

The many basalt-filled valleys that pass below present sea-level provide further evidence of a submerged shoreline some distance out to sea from the present coastline; but there is a suggestion that this shoreline is older than the 120 to 150 feet submerged shoreline. Thus, if the basalts in the Stanley-Smithton-Montague district are regarded as of similar age, then the basalt-filled valleys on Robbins Island must be older than the submerged valleys that lie between Robbins Island and Hunter and Three Hummocks Islands. Again, the Tamar has breached a basalt flow extending from Beauty Point via Garron Rock to near Georgetown. The base of this flow, whose valley section is clearly shown at Beauty Point, lies well below the present estuary level, but above its floor. Again, the basalt-filled valleys in the Wynyard-Table Cape district are considerably older than the valley which was drowned to give rise to the Wynyard Plain No depth can be suggested for this possibly older shoreline.

Origin of the Oscillating Shorelines.

It seems highly probable that these movements in the position of the shoreline are directly related to the eustatic rise and fall of sea-level during Glacial and Post-Glacial time. Lewis (1934) from his studies of the river terraces in the valley of the Derwent and other rivers in south-eastern Tasmania has shown that a definite sequence of alternating periods of high sea-level and low sea-level can be established in that part of Tasmania During the periods of high sea-level flood plains were formed at heights of 100 to 150 feet, 25 to 60 feet, and 5 to 15 feet, respectively, above present river level. During the intervening periods of low sea-level, troughs were cut in the respective flood plains to depths of 250 feet, 100 feet, and 20 feet, in each case leaving residuals of the former flood plains as paired terraces He concluded that these terraces were the outcome of the eustatic changes of sea-level during the Pleistocene and that the raised shorelines at 100 feet, 40 to 50 feet, and 10 to 15 feet, above sea-level, which he and other observers had noted, particularly along the northern coast of Tasmania and the islands of Bass Strait, were developed contemporaneously with the river terraces during the high sea-levels of the interglacial stages. On this basis he correlated the three series of river terraces and raised shorelines with the known glacial stages in Tasmania, as follows:—

Terrace System.	Age Correlation.
Uppermost terraces and beaches 100-150 ft. above sea-level.	Pre-Glacial sea-level (Pre-Malanna).
Middle terraces and beaches 45-50 ft. above sea-level	Malanna-Yolande sea-level.
Lowest terraces and beaches 5-10 ft. above sea level.	Yolande-Margaret sea-level.

This is to assume that the Pleistocene glacial stages in Tasmania were contemporaneous with the glacial stages in other parts of the world This may well have been so; but it is clear that the amount of ice involved in the glaciation of Tasmania, even at its maximum, would not have caused an eustatic rise and fall of sea-level of the magnitude concerned. Assuming that ice covered an area of 25,000 square kilometres of Tasmania to the improbable depth of 2,000 metres, then the amount of water involved would be of the order of a layer 10 centimetres thick over the surface of the ocean. In other words, the eustatic changes of sea-level which affected Tasmanian river-valleys and shore-lines were independent of the glaciation of Tasmania, and are to be correlated, therefore, with the glacial stages of the Great Ice Caps. Whether these existed contemporaneously in the Northern and Southern Hemispheres remains to be proved, but if one waxed while the other waned, then (i) the maximum possible eustatic change of sea-level would have been reduced accordingly; and (ii) the duration of the periods of high and low sea-level would have been prolonged In view of the magnitude of the observable changes of sea-level, there can be little doubt as to the broad contemporaneity of the successive glacial and interglacial stages throughout the world.

It follows then, that though Lewis was probably right in ascribing the changes of sea-level to this cause, the river terraces and marine terraces of Tasmania must be correlated with the stages of the Pleistocene as revealed in North America and Northern Europe, rather than as revealed in Tasmania, where the record is not complete. On this ground it is necessary to account for three interglacial periods of high sea-level, rather than two. Moreover, as Daly (1934) has shown, there is considerable evidence of a further eustatic fall of sea-level in Post-Glacial time, of the order of 15 to 20 feet, so that if the record is complete, we should have four sets of terraces to search for, rather than the two implied by the glacial record in Tasmania.

If Daly is correct, it seems likely that the 5 to 15 feet terraces and shore platforms have developed from the Post-Glacial fall of sea-level, in which case the 40 to 50 feet strandline may correspond to the Third Interglacial Stage (Riss-Würm), and the 100 to 150 feet strandline to the Second Interglacial Stage (Mindel-Riss). Their heights above sea-level are about the correct magnitude, judging from the figures given by Daly (1934) for such terraces in Europe, Northern Africa and Northern America.

Of the two submerged shorelines recognized in the present study, the one at 120 to 150 feet below sea-level corresponds in magnitude to the first fall of sea-level measured by Lewis (1934) in the Derwent Valley, and is older than the 40 to 50 feet raised strandline, but presumably younger than the 100 to 150 feet raised strandline. It would correspond, therefore, on the suggested correlation, to the Third or Riss Glacial Stage The pre-basaltic

submerged strandline would correspond to an earlier Glacial Stage. In the Wynyard district the pre-basaltic valleys cannot be younger than the Second Glacial Stage, since the Wynyard Plain was formed in a valley cut in the basalts The occurrence of what appears to be a remnant of a 100-feet terrace at Paloona in the Forth Valley suggests that the Forth Valley was formed during the Second or Mindel Glacial Stage. If this was so, the fact that the Forth Valley cut through the basalt sheet capping the plateau, and extending to the coastal scarp, suggests that the basalt-filled valleys passing below sea-level were probably formed during the First or Günz Glacial Stage. This suggestion must be accepted with considerable caution, however, since the basalt-filled valleys might have been brought to their present position by extensive Inter-Glacial faulting, parallel with the coastline, but located some distance inland from it.

Appendix.

Fossil Assemblage from raised beach deposit immediately south of Mt. Cameron West, near Marrawah (N W Tasmania).

FORAMINIFERA (determined by W. J. Parr).

Gaudryina cf *hastata* Parr.
Triloculina insignis (Brady)
Triloculina trigonula (Lamarck)
Bolivina sp.
Discorbis dimidiatus (Jones and Parker)
Discorbis australensis Heron-Allen and Earland.
Cibicides sp. aff *pseudoungerianus* (Cushman).
Elphidium imperatrix (Brady).
Elphidium macellum (Fichtel and Moll).

BRYOZOA (Determined by L W Stach)

Crisia acropora Busk
Cellaria setigera Pergens.
Cellaria tenuirostris (Busk).
·*Vittaticella crystallina* (Thomson).
Scuticella ventricosa (Busk).
Adeonellopsis sp
Retepora sp.

ECHINOIDEA (Determined by L W Stach)

Amblypneustes ovum pachista Clark.

The assemblages listed above are characteristic of recent shore deposits from the south-eastern Australian coast

In addition to the above forms, the following contemporaneous land forms, presumably wind blown, were present.

MOLLUSCA (Determined by C J. Gabriel)

Laoma penolensis Cox
Succinea australis Ferussac
Charopa albanensis Cox.
Flammulina marchianae Cox.

My thanks are due to these gentlemen, and to Dr. F. A. Singleton, of the University of Melbourne, for their generous help in this connection.

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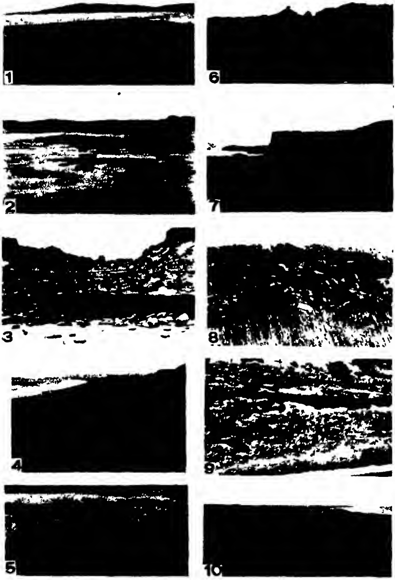
Explanation of Plates.

PLATE VIII.

1. Tree stumps outcropping at low tide at Badger Head Bay, with West Head in the background
2. Bed of peat outcropping at low tide at Badger Head Bay, with dune remnants capping the low cliff in the background
3. Bed of peat outcropping beneath the storm beach, on its seaward side, Badger Head Bay
4. Shingle ridge thrown up by storms, on the backshore at Badger Head Bay
5. Close view of the tree stumps shown in Fig 1 above
6. The transition from stationary dunes to eroded dunes, where the dunes become exposed to westerly winds blowing past Badger Head
7. Raised shore platform, 30 to 40 feet above sea level, at the south-eastern end of Half Moon Bay, Stanley Peninsula
8. Raised boulder beach capping the remnant of raised shore platform at the western end of Godfrey's Beach, Stanley Peninsula.
9. Section of raised shingle exposed in the road cutting at the Cam River.
10. Beach ridges of shingle near North Point, Stanley Peninsula.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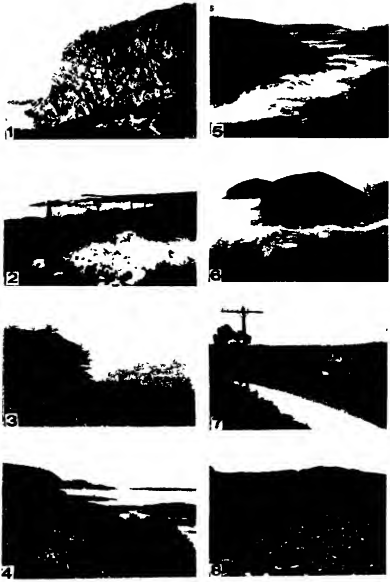

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Plate IX.

1. **Raised sea cave, 50–60 feet above sea-level, at Rocky Cape.**
2. **Rocky Cape, from midway between the Black and Detention Rivers, showing the dip slopes towards the sea, and scarp slopes to the south.**
3. **Coastline between Table Cape and Jacob's Boat Harbour, where the basalt passes below sea-level. Rocky Cape can be seen in the background.**
4. **Jacob's Boat Harbour, showing the occurrence of two raised shore platforms, one at 10–15 feet above sea-level, the other at 40–50 feet, backed by a basalt-capped scarp, representing the old cliff line**
5. **Cape Grim, showing the active formation of caves at present sea level.**
6. **The Doughboys, off Cape Grim.**
7. **The Duck River Plain, where it abuts against the scarp formed by the dolerite ridge running south from Smithton The scarp, in part at least, represents old sea-cliffs.**
8. **Shingle ridges near Woolnorth Point, with a raised shore platform in the background.**

Plate X.

1. **Circular Head, Stanley, an analcite-olivine dolerite laccolith, joined to the main part of Stanley Peninsula (right) by a Y tombolo. The hedge in the right middle-ground marks *the edge of a raised shore platform.***
2. **The main basalt ridge of Stanley Peninsula (The Green Hills) tied to the mainland by a narrow tombolo. Portions of the spits on either side of the tombolo can be seen**
3. **Raised shore platform, with capping of boulder beach, where the Green Hills basalt passes below sea level, Stanley Peninsula.**
4. **The Western Plains, Stanley Peninsula, near their junction with the Green Hills ridge. A shingle ridge, capped by sand dunes, has enclosed a small lagoon, now drained, near *the seaward edge of the raised shore platform*, and the curved spits of shingle are building out the shore.**
5. **Mount Cameron West, a "resumed" island formed by a laccolith of analcite-olivine dolerite, from the south Remains of a raised shore platform can be seen on the seaward side of the headland The dunes adjacent to the mount cap beds of Recent limestone that have been raised 25–30 feet above sea level.**

[PROC ROY. SOC. VICTORIA, 53 (N.S.), PT. II., 1941.]

ART. IX.—*Studies in the Physiology of Host-Parasite Relations.*

1. THE EFFECT OF *Bacterium solanacearum* ON THE WATER RELATIONS OF PLANTS.

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Botany School, University of Melbourne.

[Read 12th September, 1940, issued separately 26th July, 1941.]

I. Introductory.

It is proposed in this series of papers to examine selected pathological conditions in plants brought about by parasitic infection, in an endeavour to obtain a deeper insight into the physiology of host-parasite relations, with special reference to stimulation effects and wilting. For the purpose two xylem parasites, *Bacterium solanacearum* and *Fusarium lycopersici*, a phloem parasite *Aplanobacter Michiganense*, and a virus Spotted Wilt of tomato, have been selected for study. The present paper is devoted to an examination of the effect of invasion by *Bacterium solanacearum* on the water relations of host plants.

Plants infected by this organism frequently show as first symptoms epinasty of leaves, and the production of adventitious roots on the stem. Leaf epinasty is followed by unilateral flaccidity of leaflets, and finally the plant shows severe wilting. The march of transpiration and of absorption was determined during these successive phases, and correlated with the degree of invasion. The theories put forward by other workers and the belief that the wilting effect may be due to—(*a*) gum formation, (*b*) tylose formation, (*c*) toxins, (*d*) mechanical blocking, are examined in the light of these and other experimental results obtained.

II. Experimental Methods.

1. *Material.*—Tomato plants (variety Marglobe) and potato plants (variety Carman) were used as experimental material. A pure culture of *B. solanacearum* isolated from potato tubers served as the source of inoculum.

2. *The Measurement of Absorption and Transpiration.*—Weighing potometers were used for the determination of absorption and transpiration in healthy and infected plants. For experiments extending over one to two weeks (using tomato plants 8 to 9 inches in height), a tower type of potometer with vertical side-arm absorption tube was found suitable, while a small flask potometer fitted with a horizontal absorption tube served for short-term experiments using smaller plants.

Weighings of the tower type potometers were made on a transpiration balance and of the smaller flask type on a precision balance. Absorption values were obtained in each case from the calibrated absorption tubes To minimize errors due to hydrostatic pressure effects in the vertical absorption tubes of the larger potometers, the meniscus movement was limited to 3 cm before readjusting. Corrections were also made for volume variations due to temperature changes. Experimental plants were grown to a suitable size in washed sand watered with Shive's No R5 C2 solution (1915) and after the roots had been washed free of sand the plants were transferred to the potometer. The method of removal of a plant from the sand in which it had been growing was to flood the container by placing it sideways in a larger container full of water. By gentle movements of the plant the roots were then disengaged from the sand without injury, and after further washings the plant was ready for insertion in the potometer A short length of vaselined cotton wool was wound round the base of the stem which part was inserted into the appropriate slit in the rubber cork. The apparatus was then assembled, all air bubbles being eliminated The potometer flask had previously been filled with boiled and cooled Shive's solution. Luting wax was used to give a watertight seal. After setting up, the plant was left for several hours, generally overnight, to recover from any "transference reaction" Algal growth in the culture solutions was inhibited by the use of brown paper shields.

The nutrient solution was maintained in each container by means of a reservoir connected by a tap and the solution itself was changed every third day in the case of tower potometers and each day in the case of the flask potometers. In long term tests the growth of the experimental plants was quite comparable to that of plants which were kept growing in sand culture

For the determination of transpiration alone, plants were grown in metal or glazed containers, and when ready for use rubber covers were fixed in position Loss in weight over specified periods was taken as a measure of the transpiration Water was added daily to bring the containers back to their original weights. Evaporation and temperature records were kept during experiments. The plants selected for experimentation were of similar size and equal vigour. For comparative experiments they were grouped in pairs of closely similar size, and the containers were so arranged on the greenhouse bench that all were exposed to approximately the same environmental conditions.

For comparing the rates of water loss from intact leaves and leaflets of healthy and infected plants, Livingstone and Shreve's cobalt chloride method (1916) was followed, while a delicate torsion balance was utilized for comparing the rates of water loss

from detached leaflets of healthy and invaded plants. The procedure using the torsion balance was to cut off the companion leaflets, vaseline the cut ends, then weigh each as rapidly as possible. The leaflets were then suspended in still air, weighings being at hourly intervals for three hours.

3. *Leaf Area Determinations:*—When leaf areas were obtained at the close of an experiment the blue print and planimeter method was used For daily leaf area determinations in tomato and potato, the special methods developed by Porter (1937) and Clements and Goldsmith (1924) were followed. When an experiment was carried to the wilting phase of disease the turgidity of wilted leaflets was restored by floating them on water for half an hour.

4. *Inoculation Technique:*—The organism was introduced by prick inoculation into the xylem of stem or root of the test plants as specified in the text. Control plants were pricked with a sterile needle.

5. *Histological Technique.*—To facilitate estimation of interference with water movement in infected plants, the procedure was adopted of cutting off the tips of roots at the end of an experiment and placing the plants in eosin solution for half an hour. Sections for microscopical examination were then cut at the bases of all petioles and at different root and stem levels. Material for paraffin sectioning was fixed in 70 per cent. alcohol and nitric acid. This prevented the diffusion of the bacteria from the vessels. Rawlins' modification of Stoughton's method (1933) was frequently employed for staining

III. The March of Transpiration in Relation to the March of Invasion.

To obtain as complete a picture as possible of the influence of bacterial invasion on the transpiration relations of inoculated plants, experiments were carried out under three sets of environmental conditions which markedly affected the speed of invasion and the reaction of the host plant to it. These were as follows:—

(*a*) In a glasshouse during summer months (rapid invasion).
(*b*) Under deep shade conditions in a glasshouse during summer months (moderately rapid invasion).
(*c*) In a glasshouse during autumn months (slow invasion).

(*a*) Transpiration Relations when Invasion is Rapid.

Experiment 1.—Eight healthy tomato plants 9 to 10 inches in height were selected and grouped in pairs. The members of each pair were very similar in height and bore the same number of leaves. Transpiration was recorded during a preliminary two-day period, after which one plant of each pair was prick inoculated

in one bundle near the base of the stem Transpiration records were continued until the inoculated plants were wilting The results of the experiment are embodied in Table I and text figs 1, 2, and 3 During the first two days after inoculation the transpiration rate of the four inoculated plants increased relative to the controls but when tested statistically using the "t" test this increase was not found to be significant From the fourth

TABLE I—PROGRESS OF INVASION AS INDICATED BY SYMPTOMS EXPT I

EXPT PLANT	TIME IN DAYS AFTER INOCULATION					
	1	2	3	4	5	6
1 (8 leaves)	—	—	2 leaves showing unilateral wilting	3 leaves wilting 3 more wilting unilaterally	6 leaves wilting 1 leaf unilaterally wilted 1 leaf flaccid	All 8 leaves wilting
3 (9 leaves)	—	—	—	1 leaf wilting 2 leaves showing unilateral wilt 1 leaf flaccid	4 leaves wilting 2 leaves showing unilateral wilting	7 leaves wilting 2 leaves showing unilateral wilting
5 (9 leaves)	—		—	—	2 leaves showing unilateral wilting	1 leaf wilting 2 leaves showing unilateral wilting
7 (11 leaves)	—	—	—	2 leaflets on 1 leaf flaccid	2 leaves wilting unilaterally	2 leaves wilting 3 leaves wilting unilaterally

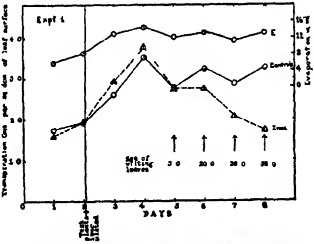

FIG 1—The march of transpiration in relation to the march of invasion when invasion is rapid Expt 1 Mean values for four control and four inoculated plants

day after inoculation a continuous decrease in the rate of the inoculated plants occurred but the difference barely became significant as determined by the "t" test, even by the seventh day after inoculation when the experiment was terminated. In this connexion it may be stated that in examining statistically the averaged results for the four test and control plants, a complicating factor is introduced by the differential speed of bacterial invasion in each inoculated plant. Thus in test plants 1 and 3, by the sixth day after inoculation most leaves were wilting and transpiration was reduced greatly below that of the controls (see text fig 2) In test plants 5 and 7 on the other hand symptoms

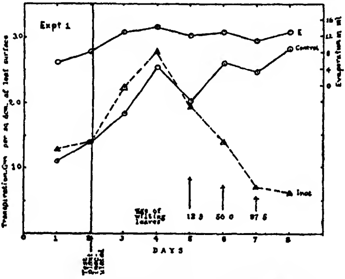

FIG 2—The march of transpiration in relation to the march of invasion when invasion is rapid Expt 1 Test plant 1 and Control

developed later and reduction in transpiration was only commencing to show by the sixth day. The experiment would have had to be continued to the tenth or twelfth day for them to reach a comparable stage of wilting to that of test plants 1 and 3. This time lag reduces the differences between test plant and control series when averaged results from day to day are taken and examined by the "t" test The results in individual cases in this experiment, and in others to be described, leave no doubt about the actual depression of the transpiration rate of the infected plants relative to the controls.

An interesting point is that little difference between the transpiration rates of the inoculated and control plants developed

until one or two leaves (out of a total of 7 to 9 on each plant) were showing some degree of wilting. This result suggested that in the early stages of wilting, increasing invasion of vessels was accompanied by increased conduction in vessels still free, while non-affected leaves connected with these transpired an increased volume of water. Other evidence on this point is presented later.

When the mean cumulative water loss by transpiration from test plants 1 and 3 and from their controls is considered (text fig. 3), it is seen that a definite reduction in the total volume of

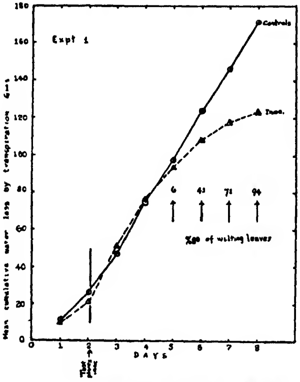

FIG 3.—Comparison of the mean cumulative transpiration losses from two healthy and two inoculated tomato plants. Expt 1

water transpired relative to the controls is becoming apparent by the fourth day after inoculation when 41 per cent. of the leaves were showing degrees of wilting. The gradual nature of the interference with transpiration is clearly shown in this graph.

In a second experiment in which a set of four inoculated and four healthy plants were used, results compatible with Experiment 1 were obtained.

(*b*) Transpiration Relations when Invasion is Moderately Rapid.

Experiment 3.—Plants were placed for the period of the experiment under dense shade conditions in a glasshouse with the object of reducing the speed of invasion and favouring the induction of epinasty. Temperature remained optimum for invasion. Epinastic response occurred in a high percentage of leaves of all the infected plants and it was found in this experiment that their transpiration rate began to show reduction one day after the development of the epinasty. This reduction became more pronounced each succeeding day that the condition persisted. Owing to the low transpiration rate under the shade conditions of the experiment, leaves remained turgid, though reflexed, until a high degree of invasion was reached.

(*c*) Transpiration Relations when Invasion is Slow.

Experiment 4.—This experiment was carried out in autumn and early winter and was designed to give information on the effect of slow invasion on transpiration. Temperature and light conditions were such as to allow fairly rapid growth of the test plants, but were sub-optimal for bacterial growth. Ten tomato plants were selected, grouped in pairs of closely similar size and their daily transpiration losses over a ten-day standardization period determined. One plant of each pair was then prick inoculated with *Bacterium solanacearum* in a vascular bundle near soil level. Transpiration losses of each grouped pair and the progress of invasion as indicated by epinastic response of leaves (Pl. XI, fig. 1), unilateral wilting and bilateral wilting of leaves were recorded during 30 days when the experiment was terminated. Results are expressed in Table II. and text figs. 4 and 5. For convenience of presentation the mean transpiration losses for each set of plants were grouped in five-day runs. Depression of the rate from infected plants relative to the controls began to be apparent by the tenth day after inoculation. This difference increased as invasion continued up to the close of the experiment when a high percentage of wilting leaves was showing in the infected plants. At the close of the experiment the difference in rates between inoculated and healthy plants was significant at the 1 per cent. level, using the "t" test. If one considers any given pair of the inoculated-control series a clearer picture is given of the effect of slow invasion on transpiration. Results for test plant 3 and its control (see Table II.) are given in text fig. 5. During the ten-day standardization period there is close agreement between the volumes of water transpired by each plant and this relation continues for a further twelve days after test plant 3 had been inoculated. By this time symptoms were commencing to develop. It was not, however, until four out of the eight leaves on the plant were showing epinastic response

that its transpiration began to drop below that of its control. It is to be noted that the water loss from the infected plant remained relatively high up to the close of the experiment, the loss from the healthy plant not being overwhelmingly greater except on days when the climatic conditions favoured high transpiration. The maintenance of this relatively high rate is believed, on the basis of eosin and section tests, to be due to the failure of the bacteria to penetrate in sufficient numbers into the freshly developing xylem vessels in the plant, so that a conducting channel between the roots and the apical leaves was kept open.

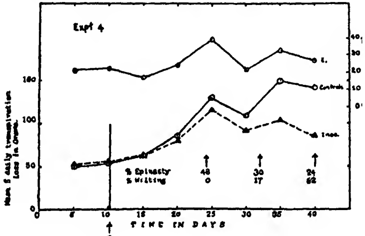

FIG. 4.—The march of transpiration in relation to the march of invasion when invasion is slow. Comparison of the five daily average transpiration from healthy and inoculated tomato plants. Expt. 4.

Results of this experiment parallel those where invasion was rapid, differing only in the prolongation of the epinasty phase and in the strong development of secondary tissues. The prolongation of the epinastic phase in the presence of increasing numbers of bacteria has an important bearing on the "bacterial" theory of wilting and will be referred to later.

To summarize the results obtained from the four experiments in this section we may say that each has shown that under varied environmental conditions—(*a*) the march of transpiration in infected plants runs parallel with that in control plants for one to two days after the appearance of well defined symptoms in the former. The depression in the transpiration rate which then bec mes evident does not appear to be directly conditioned by available leaf area; (*b*) the reduction of the transpiration rate in infected plants under all conditions of invasion is a gradual process and no sudden disturbance of this function occurs.

TABLE II.—PROGRESS OF INVASION AS INDICATED BY SYMPTOMS. EXPT. 4.

Expt Plant	Time in Days after Inoculation.					
	12	15	20	22	25	29
1 (9 leaves)	—	4 leaves showing epinasty	One leaflet on 1 epinastic leaf wilting, otherwise no change	5 leaves showing epinasty, leaflets on 2 epinastic leaves wilting	3 epinastic leaves showing unilateral wilting, 2 unchanged	4 leaves severely wilted, 3 leaves wilting, 1 epinastic; 1 normal
2 (9 leaves)	1 leaf showing epinasty	5 leaves showing epinasty	One leaflet on 1 epinastic leaf wilting, otherwise no change	Unilateral wilting in 3 epinastic leaves	No change	No change; 5 leaves normal
3 (8 leaves)	1 leaf showing epinasty	4 leaves showing epinasty	Unilateral wilting in 1 epinastic leaf, rest unchanged	Unilateral wilting in 3 epinastic leaves	No change	3 leaves wilted 3 epinastic; 2 normal
4 (10 leaves)	—	3 leaves showing epinasty	No change in epinastic leaf, 1 leaf wilting unilaterally	4 leaves showing epinasty; 1 leaf wilting unilaterally	No change	3 leaves wilted, 1 unilaterally wilted; 4 epinastic, 2 normal
5 (10 leaves)	1 leaf showing epinasty	6 leaves showing epinasty	No change	Unilateral wilting in 3 epinastic leaves	Unilateral wilting in 5 epinastic leaves	8 leaves wilting, 1 flaccid, 1 normal

COMPARISON OF HOURLY TRANSPIRATION RATES OF CONTROL AND INFECTED PLANTS AT THE INCIPIENT WILTING STAGE.

During the two days in which wilt symptoms were developing in test plants 1 and 3 of Experiment 1, a comparison of their hourly transpiration rates with those of their controls was made (text fig. 6). Both inoculated plants appeared fresh and normal at 8 a.m. when the hourly observations were commenced. By 12 noon two leaves of test plant 1 were wilting and one was flaccid, while in test plant 3 one leaf was wilting and two leaves were showing commencement of unilateral wilting. By 2 p.m. the picture was much as set out in Table 1, column 4. Turning to the transpiration record (text fig. 6) it may be observed that on the first day the transpiration rates of the control and inoculated plants rose by almost equal increments of rate until 11 a.m. During the period 11 a.m. to 1 p.m. the controls transpired at a considerably higher rate. It was during this period that flaccidity was becoming evident in certain leaves of the inoculated plants. Between 1 and 2 p.m. the transpiration of inoculated plants showed a greater increase relative to the controls, but between 2 and 3 p.m. with evaporation still increasing, the inoculated plants showed a decrease of 27 per cent. relative to the preceding hour's rate, while the transpiration rate of the

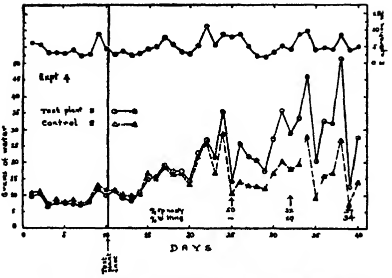

FIG 5 —Comparison of transpiration from a healthy and an inoculated plant under conditions of slow invasion Expt 4 Test plant 1 and Control

controls continued to rise From 3 to 4 p m the rates of transpiration in both sets were decreasing but the relative decrease was 10 per cent greater in the controls In the record for the following day the only noteworthy feature was a repetition of the rate increase of the infected plants relative to the controls (22 per cent 2 5 per cent) during the 1 to 2 p m period A possible explanation of these effects is that with the commencement

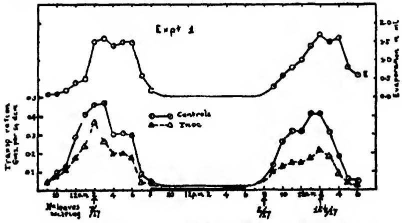

FIG 6 —The daily march of transpiration in healthy and inoculated plants when bacterial wilting is just commencing Mean values for Test plants 1 and 3 and their Controls Expt 1

of bacterial wilting the stomata open more widely and the transpiration rate rises steeply for a short time after the manner described by Knight (1922) for plants wilting from lack of water. It is suggested that the subsequent earlier fall in the transpiration rate of infected plants may be due to the fact that a transpiration-limiting water content of the mesophyll cells is reached more rapidly in the infected plants than in the controls owing to the operation of two factors:—(*a*) The more widely open stomata during the preceding phase, and (*b*) the interference with the conduction of water to the leaves Further investigation of these effects is being made with special reference to stomatal movements during the wilting phase.

The graph also shows that both in healthy and infected plants the hourly march of transpiration follows the normal course observed for many herbaceous plant types. In the healthy plants it is evident that the rate of transpiration increased more rapidly than the rate of evaporation, as registered by the atmometer, until a maximum was reached and the later increase in the exaporating power of the air was not reflected in the rate of water loss The curves also show that transpiration increases rapidly during the daylight hours when the stomata are open and falls very low during the night hours when the stomata are closed The overnight restoration of turgidity in wilting leaflets of infected plants is due to this decrease in transpiration.

Observations on Temporary Overnight Recovery of Turgidity in Flaccid Leaves.

During the course of the above experiments it was observed that leaflets of plants which become flaccid or wilted during the day often recovered their turgidity during the night. This recovery from flaccidity after a second day was frequently repeated during a second night, but usually by the third day the wilting became irreversible Typical examples of this temporary recovery in infected plants are recorded in Table III. This recovery is of course due to the fact that the water-content of the flaccid or wilted leaves builds up overnight while transpiration is reduced, but the effect is important in relation to certain theories advanced on the cause of bacterial wilting and the bearing of these observations on this wilting effect will be considered in Section VII.

IV. Comparison of the Rates of Transpiration from Companion Leaflets during Epinasty.

The epinastic response of leaves of infected plants, which has been referred to in connexion with Experiments 1 to 4, has been shown in an earlier paper (Grieve, 1939) to be conditioned by the path of invasion and generally to be associated with the

presence of bacteria at the base of the petiole. Depending on the speed of invasion, leaf epinasty is followed sooner or later by unilateral wilting of leaflets. Data presented in Section III. showed that transpiration began to decline one or more days after the development of epinasty and usually not until one or two

TABLE III.—OBSERVATIONS OF TEMPORARY OVERNIGHT RECOVERY OF TURGIDITY IN WILTING LEAVES OF INOCULATED PLANTS. DATA FROM EXPT. 3. LETTERS DENOTE LEAVES; *a* = LOWEST ON STEM.

—		Days after Inoculation.			
		4	5	6	7
Test Plant No. 3. (8 leaves)	9 a.m.	Leaves *b*, *c* and *d* showing epinasty	Leaflets of *d* turgid	All leaves turgid	Leaves *d* and *e* turgid, leaf *g* unilaterally flaccid, leaf *b* unilaterally wilted
	11 a.m.	No change	Unilateral wilting in leaf *d*	Unilateral wilt developing in leaves *b*, *d* and *g*	
	1 p.m.	Unilateral wilting in leaf *d*	No change	Unilateral wilt in leaves *b*, *d*, *e* and *g*	
	3–5 p.m.	No change	Unilateral wilting in leaves *b*, *d*, and *g*.	No change	Leaves *b* and *d* wilting bilaterally; leaves *e* and *g* unilaterally
	7 p.m.	Leaflets of *d* almost turgid	Leaflets of *d* almost turgid, leaflets of *b* and *g* still flaccid	No indication of recovery	No recovery
Test Plant No. 4. (9 leaves)	9 a.m.	Leaf *b* showing epinasty	No change from preceding day	All leaves turgid	Leaves turgid except *b* which remained flaccid
	3 p.m.	No change	Unilateral wilting commencing in leaves *b*, *e* and *g*	Unilateral wilting in leaves *b*, *e* and *g*	Leaves *b* and *e* wilting bilaterally; leaves *c* and *d* showing epinasty, while *f* and *g* show unilateral wilting
	7 p.m.	No change	All leaves recovered turgidity	No change	No change

leaves of a plant were wilting. It therefore appeared desirable to compare transpiration rate in companion leaflets of leaves showing epinasty or unilateral wilting and to relate the results obtained to transpiration relations discussed in the preceding section. At the outset, determinations were made on companion leaflets of healthy tomato and potato plants in order to find the degree of variation in transpiration rate between such leaflets.

Experiments on such companion leaflets using both the "three colour strip" method and the torsion balance method showed that the differences in rate between them were comparatively small (Table IV). Determinations were next made on companion leaflets of leaves showing epinasty. The results (Table IV.) were examined statistically by the "t" test and showed that at the 1 per cent. level there was a significantly lower transpiration rate from one companion leaflet of a pair in plants showing leaf epinasty. Sections and eosin test showed the side with the reduced rate to be the invaded side. These experiments made it plain that some increase in transpiration rate must have occurred either in other leaves on the plant or in non-affected companion leaflets in a leaf showing epinasty, to account for the maintenance of transpiration rate which has been recorded in Expts. 1 to 3. It was not found practicable, however, to ascertain by the above methods whether part of this compensatory increase took place in the non-invaded side.

TABLE IV.—COMPARISON OF THE RATES OF WATER LOSS FROM COMPANION LEAFLETS (A, B) OF HEALTHY PLANTS AND FROM COMPANION LEAFLETS OF INFECTED PLANTS SHOWING LEAF EPINASTY (IN INFECTED PLANTS A = INVADED SIDE.)

(*a*) *Torsion Balance Experiments.*
Water loss in mgms. per sq. cm. per hour.

Tomato.				Potato			
Healthy.		Infected.		Healthy		Infected.	
1A	0·56	1A	0·22	1A	1·01	1A	0·25
1B	0·49	1B	0·60	1B	0·96	1B	0·59
2A	0·40	2A	0·48	2A	0·83	2A	0·29
2B	0·39	2B	0·47	2B	0·83	2B	0·41
3A	0·30	3A	0·21	3A	1·06	3A	0·98
3B	0·24	3B	0·58	3B	1·06	3B	0·86
4A	0·41	4A	0·36	4A	0·28	4A	1·84
4B	0·55	4B	0·69	4B	0·31	4B	2·23
5A	1·26	5A	0·37	5A	0·47	5A	0·90
5B	1·14	5B	0·53	5B	0·38	5B	1·09
6A	1·60	6A	0·33	6A	0·26	6A	0·15
6B	1·60	6B	0·50	6B	0·23	6B	0·40
7A	0·17	7A	0·17	7A	0·25	7A	0·18
7B	0·18	7B	0·82	7B	0·35	7B	0·26
8A	1·78	8A	1·12	8A	0·27	8A	0·72
8B	1·77	8B	1·00	8B	0·26	8B	0·56
9A	0·81	9A	0·40	9A	0·11	9A	1·41
9B	0·60	9B	0·68	9B	0·13	9B	2·90
10A	0·81	10A	0·20	10A	0·25	10A	0·17
10B	0·23	10B	0·30	10B	0·23	10B	0·39

TABLE IV.—*continued.*
(*b*) *Cobalt chloride method*
POTATO

Healthy			Infected					
1A	40	seconds	1A	180	seconds	6A	180	seconds
1B	40	,,	1B	55	,,	6B	60	,,
2A	60	,,	2A	180	,,	7A	115	,,
2B	55	,,	2B	55	,,	7B	30	,,
3A	45	,,	3A	105	,,	8A	145	,,
3B	40	,,	3B	47	,,	8B	117	,,
4A	160	,,	4A	90	,,	9A	210	,,
4B	167	,,	4B	30	,,	9B	175	,,
5A	63	,,	5A	180	,,	10A	145	,,
5B	60	,,	5B	30	,,	10B	60	,,

V. The Effect of Invasion on Transpiration/Absorption Relations.

The wilting effect has so far been examined only in relation to water loss. Since theories of wilting in relation to bacterial invasion have postulated a breakdown of the absorption mechanism it was necessary to ascertain the effect of invasion on water uptake. In the following experiments absorption and also transpiration rates were recorded using potometer types A and B described under Methods. Initial experiments dealt with the relation between the rate of absorption and of transpiration in healthy tomato plants. The problem of water balance has received attention from various workers. Thus Montfort (1922) using the potometer, investigated the relationships between transpiration and absorption in *Zea mays* and *Impatiens parviflora* grown in Knop's solution and on transfer to peat and bog water He found the transpiratory quotient (T/A) in Knop's solution and in peat and bog water to be generally greater than unity Lachenmeier (1932) on the contrary found for *Veronica beccabunga* and *Myosotis palustris* that absorption exceeded transpiration both in light (artificial) and dark, or T/A was less than unity. Kramer (1937) recorded for sunflower plants growing in nutrient solution, that transpiration frequently exceeded absorption during the day, but that the positions were reversed during the night. The result of a typical experiment with healthy tomato plants is shown in text fig. 7. It is seen that under the conditions of these experiments in a warm glasshouse, transpiration generally exceeds absorption during the day while absorption is always greater than transpiration during the night. These results are in closest accord with those of Kramer who also worked under glasshouse conditions. It may be noted here, however, that in later experiments carried out under artificial light, results approximating to Lachenmeier's were obtained (see Section VI.). In the above experiments readings and weighings were taken at 9 a.m. and at 5 p.m. giving the comparison between absorption and

transpiration during the day and night periods, but for the longer experiments now to be described, in which the march of these two functions was followed in connexion with invasion, values were recorded for 24 hour periods, readings being taken at 9 a.m. each day. Each plant served as its own control, 24 hourly readings of both water uptake and water loss being taken for some days before inoculation and continued until epinasty and wilting effects were visible after inoculation. Root and apical stem inoculations were practised in different experiments in order to differentiate between the effect on absorption of the presence or local absence of bacteria.

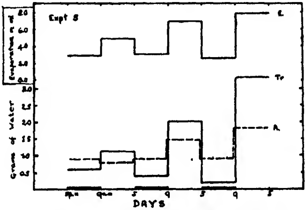

FIG 7.—Rates of absorption and transpiration in healthy tomato plants during the day and night. Expt. 5.

(*a*) *Root Inoculation.*—Typical results are expressed in text figs 8 and 9 No record of evaporation was kept for these experiments The temperature record however, showed little variation and it has been observed in other experiments where both evaporation and temperature records were kept, that the curves followed roughly a parallel course. Consequently the falling transpiration and absorption rates shown in the later stages of the experiments were not due to changing environmental conditions but to the effect of the disease. Study of the text figures shows that there is no sudden interference with the absorption of water but that there is a gradual decrease in rate as the disease progresses. The plants were sectioned at various root and stem levels at the close of the experiments after being tested for eosin uptake through cut root tips. Examination then showed that the rate of absorption in the final stages was much higher than what might have been expected having regard to the number of vessels not conducting eosin. Thus in Experiment 9 (text fig. 8) for example, the absorption was 0.50 gms. over

24 hours (50 per cent. of its mean value up to inoculation) at a time when by eosin test it was shown that more than three-quarters of the total number of vessels of the main root were unable to conduct water. Similarly, conduction of water through the stem as judged by transpiration, was high in relation to the number of vessels still able to conduct as shown by eosin test. These observations link up with those of Section III.

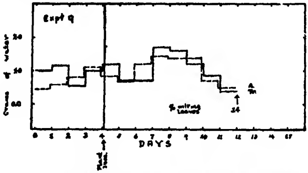

FIG 8.—The effect of invasion by *B solanacearum* on the transpiration and absorption of a tomato plant Plant inoculated at base of stem. Expt 9

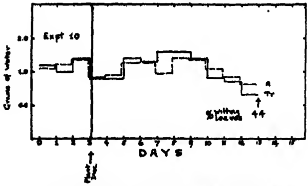

FIG 9.—The effect of invasion by *B solanacearum* on the transpiration and absorption of a tomato plant. Plant inoculated at base of stem. Expt. 10.

(*b*) *Apical Inoculation:*—This type of experiment was designed to determine whether any toxin or toxic substance produced by bacterial action could pass down to the roots and interfere with the absorption of water. A potato plant was used in one experiment, the inoculation point being high up on the stem. The experiment was carried on for four days by which time epinastic response but no wilting was showing in three apical leaves. The experiment was then stopped and an eosin and sectional analysis of the plant showed that the bacteria had grown

back down the vessels to the base of the stem but had not reached the roots. Just below the point where bacteria were present a certain amount of localised gum formation had occurred in and around vessels. Examination of the absorption rate (text fig. 10) shows that no depressant effect was exercised on the absorptive power of the roots by the bacteria growing back through the stem vessels. The results of this and other apical inoculation experiments taken in conjunction with the results for root inoculation experiments described earlier, indicate that the cause of wilting in tomato and potato plants is other than protoplasmic intoxication of root cells leading to reduced osmotic pressure and decreased absorption as was suggested by Hutchinson (1913).

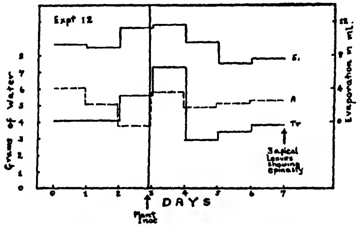

FIG 10.—The effect of apical stem inoculation by *B solanacearum* on transpiration and absorption in a potato plant. Expt 12

VI. The Effect of Artificially Reducing Leaf Area on Transpiration/Absorption Relations.

Results presented in Section III indicated the development of a compensatory higher transpiration rate from unaffected leaves on infected plants to offset the reduction in rate in wilting leaves. To find whether this effect was the normal reaction of healthy plants on the reduction of their available leaf area the following experiments were performed. Transpiration/absorption rates in healthy tomato plants were determined using suitable potometers and then half or whole leaves were vaselined and the effect of this reduction in effective leaf area on the transpiration rate determined. Flask type potometers were used and the work was carried out in an insulated room, the illumination being provided by a 500 watt lamp. The tomato plants used were between five to seven inches in height, having six to eight well-expanded leaves. They had been grown in containers filled with washed sand and

watered with Shive's solution. After setting up in the potometer, using the procedure described under Methods, the plant was left for several hours, usually overnight, in the insulated room before an experiment was commenced. Further details of experimental technique with the small flask potometers may be given. The total weight of the potometer, nutrient solution and plant was approximately 180 grams. The balance used could carry up to 600 grams load and was sensitive to 8 mgms. The absorption was read off on a millimetre scale pasted along the absorption tube, and, after a correction for volume changes due to slight unavoidable rises in temperature had been applied, could be recorded in grams as the absorption tube in each potometer was carefully calibrated, using mercury. Experiments were first carried out to ascertain the normal absorption/transpiration relations in tomato plants under the conditions of these experiments It was found that absorption tended to exceed transpiration slightly both in light and darkness These results agree with those obtained by Lachenmeier for *Veronica beccabunga* and *Myosotis palustris* under similar experimental conditions. They differ from the results obtained under glasshouse conditions (Section V.) where absorption was found mainly to exceed transpiration only during the night. Absorption/transpiration values were next obtained at half-hourly intervals for a period of two to three hours, after which one half leaf or a complete leaf was vaselined on both surfaces. After vaselining a leaf in any experiment the plant was left for an hour before readings were resumed. Typical results are presented in text figs 11 and 12. Vaselining of one leaf (fifth from base—nine leaves on plant) in Expt. 17 (text fig. 11) reduced the total leaf area by 18 2 per cent. and yet no reduction in the rate

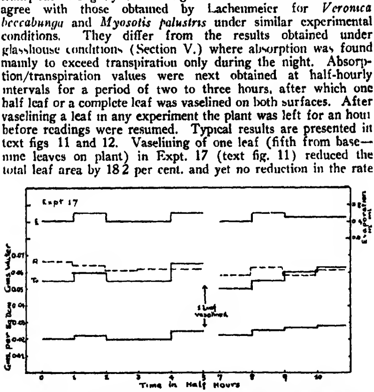

FIG 11 – Effect of vaselining one leaf on transpiration and absorption in tomato. Total number of leaves on the experimental plant was nine, and the fifth leaf from the base was vaselined. Original leaf area was 2.68 sq. dcm. and 2 19 sq dcm. after one leaf was vaselined. Expt 17

occurred. In another experiment (No. 27) where one leaf (fourth from base—eight leaves on plant) was vaselined the reduction in leaf area was 28 per cent. and again no reduction in the rate of transpiration occurred. Text fig 12 shows results obtained in two experiments when two and three half leaves respectively (cf., unilateral wilting in infected plants) were vaselined The rate of transpiration under constant environmental conditions is more than maintained despite the reduction in leaf area These results confirm the observations arising out of the

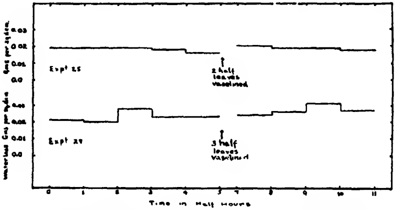

FIG. 12 - Effect of vaselining half leaves on the rate of transpiration Expt 25 Total number of leaves on the tomato plant was nine and half leaves of the 4th and 5th from the base were vaselined Original leaf area was 3.66 sq dcm, residual area 2.89 sq dcm Expt 28. Number of leaves six, half leaves of 2nd, 3rd and 4th from base vaselined Original leaf area = 2.79 sq dcm, residual leaf area 1.89 sq dcm

study of transpiration rate in relation to bacterial invasion and wilting, in that they demonstrate that the rate of water loss may be maintained despite the reduction of available leaf area ranging up to 33 per cent in the experiments so far reported. Since the experiments were carried out under controlled conditions of temperature and light it is clear that the supply of water to and the transpiration of water from the remaining leaves must have been increased Reference to this effect occurs in Maximov's book *The Plant in Relation to Water* (p 121, 2nd imp., 1935) He states " It has frequently been observed that if a portion of a plant is divided into separate pieces the intensity of transpiration is markedly increased. Famintsin (1883) in his book on the metabolism of plants cites the following experiment performed by his pupil Krutizky A hawthorn shoot with eight leaves transpired 8 gm. of water a day; one with five leaves 5.2 gm.; and a shoot with only one leaf 4.9 gm. One the basis of the amount transpired in the third case, the first shoot should have transpired 39.2 gm. instead of 8 gm. and the second 24.5 gm. instead of 5.2 gm. This can only be explained by supposing that as leaves are successively removed from a shoot, the supply of water to the remaining still attached leaves is increased."

The chain of events involved in the increased supply of water to unaffected leaves in plants in which one or two leaves had been vaselined, may be visualized as follows, assuming the plant to be growing under conditions of constant light and temperature and to be well supplied with water. In the diagram (text fig 13) A and B represent cells of two leaves which are served by vascular bundles which join at D, and C represents a cell in contact with the xylem of the root We know that when a plant is transpiring

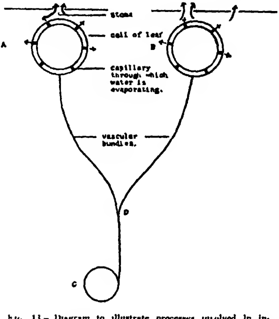

FIG. 13 – Diagram to illustrate processes involved in increasing transpiration intensity with decreasing leaf area See text.

a gradient of suction pressures is developed in the cells from the leaves down to the roots The suction pressures developed at A and B may be assumed to be approximately equal and will be higher than the suction pressure at the point of water supply C. Consequently water will be drawn up through the stem vessels and approximately equal volumes will travel to cells A and B. The two leaves will be transpiring at rates proportional to the saturation deficit. Owing to the competition between them for water from C, however, the minute capillaries in the walls of the mesophyll cells A and B will not be completely filled with water and the outer layers of the cell walls will tend to dry. Under these conditions evaporation will be reduced. Now, if one leaf A be vaselined, exaporation is prevented and its cells show increasing turgidity. Applying the equation $S = P-T$, when $S =$ suction

pressure, P = osmotic pressure, and T = wall pressure, it is clear that with increasing turgidity the suction pressure of cell A falls and finally the value of this approximates to the suction pressure of the water-supplying cell C, and no further water is drawn to cell A Owing to the decreasing water demand from A, the suction pressure of cell C also falls as it becomes more turgid This leads to the establishment of a greater suction pressure gradient between leaf cell B and the cell C The net result is that a greater volume of water than before is drawn to cell B. As this cell shows increasing turgidity owing to the increased water supply, the water menisci in the minute capillaries in the walls of the mesophyll cells move outwards as the capillaries become filled with water, and finally there may even be liquid water present on the outside of the cell walls Evaporation would then increase, occurring as from a free water surface in a vessel filled to the brim, and the gradient of suction pressure between B and C would be maintained in sufficient degree to cause the more rapid flow of water to B

In infected plants where the bacteria are gradually filling vessels leading to one of two leaves, a somewhat similar chain of events may be postulated The suction pressures of the cells of the leaves below which bacterial blocking is occurring, would of course rise, as less water passes to them, but as this force cannot be transmitted down to the point of water supply, the net result is that an increasing volume of water passes to the free leaf as the osmotic mechanism described above comes into play

VII. Discussion of Results and their Bearing on the Physiology of Bacterially Induced Wilting.

It has been demonstrated in the preceding experiments that there is a progressive interference with the transpiration and absorption in infected plants as wilting of leaves increases. It is necessary now to interpret the experimental results obtained more closely in terms of the actual cause or causes of the disturbance of the water relations of the invaded plant. The history of investigations bearing on this point may here be considered

Historical Survey.—Hunger (1901), from his examination of infected tomato and tobacco stems, concluded that the wilt was caused by the plugging of the vessels by the bacteria He stated further that tyloses were abundant in the vessels of diseased tomato plants and believed that these structures, which apparently were induced by parasitic attack, helped to prevent the upward transport of water to the leaves Hutchinson (1913), in a paper on Rangpur Tobacco Wilt caused by *B solanacearum* in India, discounted the hypothesis that wilting was due to parasitic plugging of the vessels, in the case, at least, of tobacco wilt. From his observations on the disease and from experiments that he carried out, he was led to attribute the wilting effect to the action

of secreted toxins from the parasite on the cell protoplasm. His evidence may be summarized as follows.—1. Bacteria are not present in sufficiently large numbers in the vessels of wilted plants to cause any serious interference with the water supply of the plants. 2 A healthy tobacco plant may be cut half through the stem without causing wilt even in the leaves immediately above the cut 3. An alcohol precipitate from a bouillon culture when dissolved in sterile water and fed into the vascular system of a healthy plant caused wilt in the course of a few days; when boiled it had no effect He believed that the real explanation of wilting in relation to failure of water supply was that in the earlier stages of the disease at least, toxins produced by the organism caused protoplasmic intoxication leading to lowered osmotic pressure in the root system In the later stages of the disease the water supply would be further interfered with by the formation and accumulation of gum masses in the vessels. Van der Meer (1929), who has done the most detailed work on this subject, carried out a number of experiments to ascertain the cause of wilting in infected tomato and tobacco plants and concluded that no one factor was responsible The abridged account she gives in English of the results of her investigations on this point reads as follows " In which way will the bacteria influence the water supply in a plant? Possibly the co-operation of the factors mentioned in the different theories, results in a deficit of water These factors may be: (1) root damage, (2) substances secreted by the parasite in the vessels, upon which the plant reacts by gum-formation and discolouration of the vessel walls, (3) accumulation of bacteria here and there in the vessels"

The present investigation into the cause of wilting in the case of tomato and potato plants invaded by *B. solanacearum* will be considered under the following headings.—(1) gum formation, (2) tylose formation, (3) toxin production, and (4) mechanical blocking.

(1) *Gum Formation*.—Observations were made on the presence or absence of gum in the test tomato and potato plants used in the experiments described earlier in this paper and the possibility examined of this substance being concerned. In no case did the amount of gum present in the stem and petiolar vessels suggest the possibility of mechanical interference. Gum formation was in fact of much rarer occurrence in the vessels than in the cells surrounding the bundle groups. Gum formation was also more commonly observed in cortical cells and in cells of the interfascicular cambium than in the vessels. Its occurrence here was surprisingly localised. One transverse section of a stem or root would show gum in the cells while the next serial section would fail to show it. Longitudinal sections showed that the gum formation in the vessels was of sporadic occurrence and not in amounts sufficient to cause blockage. Experimental evidence, particularly from the absorption experiments, indicated that such

gum as was present in cells and vessels of the stem and root did not affect the passage of water. In experiments where apical inoculation was practised, gum appeared in root vessels and cells ahead of the bacteria which were multiplying and growing downwards in the xylem, and yet no obvious interference with the absorption of water occurred at that stage. Again eosin passed rapidly up through vessels in, or around which, gum formation was evident, but in which no bacteria were present Van der Meer (1929) gives no data on the occurrence of gum in infected tomato plants, but apparently bases her conclusion that gum formation is involved in interference with water supply on experiments in which cut tomato seedlings were placed in the filtrate of beef-broth cultures of *B. solanacearum*. Her observations are as follows —" After 12 hours there was no wilting to be observed, but cross sections of the tomato stems from the bacterial filtrate showed that the walls of some vessels were discoloured yellow and that some vessels contained gum." The occurrence of gum in some vessels after such treatment is not surprising, but the critical point is that no wilting was observed, so that her conclusion is regarded as being invalid in the case of tomato plants. Similar experiments to those above have been made by the author (Grieve, 1939), and again no wilting has been observed in the presence of gum formation; consequently for this reason and for the more cogent reasons adduced above, it is concluded in the case of tomato and potato plants invaded by *B solanacearum* that gum formation in cells and vessels is not causally concerned with the interference with the water relations of such infected plants. The strain of *B. solanacearum* used would not infect tobacco, so that no attempt could be made to confirm the conclusions of Hutchinson and Van der Meer for this plant. There is, however, some evidence that the degree of gum formation and possibly its blocking effect is dependent on the host plant Thus in *Impatiens balsamina* large amounts of gum have been observed in the vessels and it is hoped later to investigate its importance here.

(2) *Tylose Formation* —The procedure adopted in investigating the incidence of tyloses was to cut transverse and longitudinal sections of the stems and roots, wash out the bacteria from the invaded vessels and then examine for the presence of these structures. Tylose formation does occur, but in only one isolated case where one bundle of a potato plant showed four to five vessels with well developed tyloses was there any real possibility of interference with water movement. In the vast majority of plants examined, the tyloses were small structures just showing as minute protuberances in relation to the size of the vessel at the time of onset of the wilting phase. The conclusion reached is that in tomato and potato plants tylose formation was not causally related to wilting and the disturbance of the water relations of the plant.

(3) *Toxin Production:*—Hutchinson's theory that wilting is due to toxins causing protoplasmic intoxication leading to lowered osmotic pressure is considered to be untenable, as far as the plants worked with by the author are concerned since (*a*) no confirmation of the presence of a toxin has been obtained on repeating Hutchinson's type experiment (Grieve, 1939); (*b*) absorption rate is not reduced when the bacteria are growing back from the top of the stem after apical inoculation until they are present in great numbers. If a toxin were involved and Hutchinson's view was correct, wilting due to lowered absorption should have occurred before the bacteria actually were present in the roots; (*c*) flaccid or even wilted leaflets of invaded plants recover overnight in the early stages of invasion (see Table III), and (*d*) wilted leaves on being cut off and placed in water recover their turgidity Such recovery could not occur in the continuous presence of a toxin. The example given under (*d*) indicated that the wilting effect is due simply to a temporary shortage of water During the day water is lost more rapidly from the affected leaves than it can be made good through the partially invaded vessels. During the night reduced transpiration allows of building up of the water content of such leaves. The conclusions given here apply to tomato and potato and not to tobacco plants, but it is of interest to observe that Van der Meer applied the same criterion of recovery from wilting in discussing the possible occurrence of a toxin in invaded tobacco plants. She writes "If *B. solanacearum* secreted substances which poisoned the parenchymatic cells of the leaves, in my opinion a limp leaf had to persevere in its condition, when the vessels were experimentally enabled to transport water This observation suggests, that the inability of the xylem in the stem to transport sufficient water to the leaves has caused wilting, and contradicts the explanation of Hutchinson that the wilting symptoms of slime-disease would have been caused by protoplasmic intoxication and decreased osmotic pressure" In view of the result of this experiment and of others in which she was unable to confirm Hutchinson's results it is surprising to find she is unwilling to abandon the concept of toxin action in tomato and tobacco plants.

(4) *Mechanical Blocking*:—A considerable body of evidence regarding the part played by the bacteria in causing wilting by mechanical blocking, has been accumulated during the course of experiments extending over several seasons. At the close of all experiments when infected plants were showing epinasty or wilting, the procedure was adopted of cutting off the tips of their main roots and placing them in a solution of eosin for half an hour. Thin hand sections were then cut at the bases of petioles and stems, and roots were either sectioned at various levels or subjected to the maceration methods described elsewhere (Grieve, 1936). The results of some of these observations are embodied

in Tables V. and VI which give the section analysis in the case of test plants used in certain of the transpiration experiments reported earlier in this paper The picture for test plants 1 and 3 of Expt 1 (Table V) is one of almost complete occlusion of vessels by the invading organism The degree of bacterial blocking was not as great in test plants 5 and 7, the slower reduction of transpiration rate and the freshness of certain apical leaves in these plants at the close of the experiment reflects the lesser degree of blocking The eosin and sectional analysis showed that some few vessels in the large vascular bundles escaped invasion and sufficient water was transported from the roots to the apical leaves to keep these turgid Strong bleeding developed from the roots of these test plants and indicated that where mechanical blocking was not complete the absorbing

TABLE V—DISTRIBUTION OF BACTERIA AND THE DEGREE OF BACTERIAL BLOCKING AS DETERMINED BY SECTIONING AFTER EOSIN TRANSPORT TEST, EXPT 1, CORRELATE WITH TABLE I

	Test Plant			
	1	3	5	7
Base of leaves	*a* Vessels of all bundles completely blocked with bacteria *b* Vessels of all bundles completely blocked with bacteria *c* Vessels of all bundles completely blocked with bacteria *d* Vessels of all bundles completely blocked with bacteria *e* Vessels of all bundles completely blocked with bacteria *f* Vessels of all bundles completely blocked with bacteria *g* Vessels of all bundles completely blocked with bacteria *h* Slight invasion of one lateral bundle	*a* All bundles blocked *b* All bundles blocked *c* All bundles blocked *d* All bundles blocked *e* All bundles blocked *f* One lateral and the central bundle completely blocked Only 2 3 vessels in other laterals blocked *g* All bundles blocked *h* Both laterals blocked central bundle free *i* Slight invasion of all bundles	*a* Both laterals blocked, central free *b* Both laterals blocked, central free *c* Both laterals blocked, central free *d* All bundles completely blocked *e* Unilateral invasion *f* Heavy invasion, but eosin able to pass *g* Unilateral invasion *h* Unilateral invasion *i* Unilateral invasion	*a* Both laterals blocked, central free *b* Both laterals blocked, central free *c* All bundles blocked *d* Unilateral invasion *e* All bundles blocked *f* Bacteria present but not in blocking numbers *g* Heavy unilateral invasion *h* Slight bilateral invasion *i* Slight invasion *j* Slight invasion *k* Slight invasion
Stem	Section cut at level of *d* showed complete blocking of two large bundles and of three small bundles In the third bundle only a few vessels showed eosin	Section at level of *c* showed two large bundles and the three small ones completely blocked Sections at level of *e* and *h* showed same degree of blocking	Section at level of *d* showed eosin present in 5 6 vessels of each bundle, the rest being blocked	Section at *e* showed bacteria blocking all the earlier formed vessels Vessels nearer the cambium showing eosin. Section at *j* showed bacteria in one large bundle
Root	Slight watery exudate Heavy blocking of most vessels	Slight watery exudate Bacteria present in blocking numbers in most vessels	Strong watery exudate from two bundles. Bacteria present but not in blocking numbers, one bundle completely blocked	Strong watery exudate. Bacteria present but not in blocking numbers

TABLE VI.—DEGREE OF BACTERIAL BLOCKING AS DETERMINED BY EOSIN TEST AND SECTIONING AT CLOSE OF TRANSPIRATION EXPT. 4

Test Plant Number	4	8	9	10
Leaves .	*a*, *b*, *c* All bundles blocked and considerable breakdown of xylem *d* Both laterals blocked, central free *e* One lateral and central bundle blocked, lighter invasion in other lateral *f* One lateral and central bundle blocked, lighter invasion in other lateral *g* One lateral and central blocked, eosin in other lateral *h* Eosin in all bundles Bacteria in vessels of one lateral *i* One lateral and central blocked *j* Central bundle only blocked, eosin in laterals	*a*, *b*, *c*, *d* All bundles blocked by bacteria *e* Both laterals and central bundles invaded, but eosin was able to pass *f* All bundles completely blocked *g* Half the vessels in one lateral blocked Rest of vessels in this bundle and vessels in other bundles passed eosin *h* Slight invasion of all bundles *i* One lateral heavily invaded, other lateral free of bacteria but no eosin passing due to blocking lower down in the stem	*a*, *b*, *c*, *d*, *e* Complete blocking of vessels *f* Only 2–3 vessels invaded in one lateral, all other vessels showing eosin *g* Both laterals and central blocked *h* One lateral blocked, other lateral free of bacteria and showing eosin *i* One lateral and central bundle blocked other lateral only partially blocked *j* *k* All bundles blocked *l* *m* One lateral and central bundle blocked	*a*, *b*, *c*, *d*, *e* All bundles completely blocked *f* One lateral blocked *g* All bundles blocked *h* One lateral and the central bundle blocked *j*, *k*, *l*, *m* Fairly heavy invasion
Stem	Section at level of *d* showed one large bundle quite blocked A second large bundle was heavily invaded and the third only slightly	Level of *d* A few vessels of each bundle allowed passage of eosin, the rest being blocked by bacteria	Level of *g* Eosin was present only in one large bundle, the others being blocked	Eosin passing in a few vessels of one large bundle at level of *f*
Root ..	Not recorded	Not recorded	Bacteria heavily invading vessels down to 2 inches below soil level	Bacteria filling approximately 30 per cent of larger vessels

mechanism was not affected by the presence of bacteria or their metabolic products An illustration of the degree of blocking commonly recorded when the statement "all bundles completely blocked" is made in the tables, may be seen in Pl. XI, fig. 3 The typical degree of blocking associated with epinastic response of leaves is illustrated in earlier papers (Grieve, 1936, 1939). The details given in the 1939 paper apply as well to the physiology of wilting although that aspect of interpretation was not there stressed The data presented above is considered to provide conclusive evidence for the mechanical blocking theory in the case of tomato and potato plants.

It is of value here to consider results and interpretations of other workers. Van der Meer (1929), while not using the refinements of technique here employed in assessing the value of blocking, nevertheless made many careful observations She

employed an eosin transport test followed by "barking" of the stem to observe the movement of eosin, and sectioning to determine the presence or absence of bacteria. Unfortunately her observations on the presence or absence of bacteria at the bases of leaves are limited to +, ++ or — signs, no clear indication of numbers present being given. Furthermore no information is contained in her tables on the occurrence of bacteria in the stem; consequently it is not possible to determine any relation between the bacteria in the vessels, the transport of eosin and the wilting of leaves in the tomato plants she used. Conclusions reached by Van der Meer, however, are as follows:—(*a*) Leaves can be turgid, although *B. solanacearum* be present in petiole and lamina, (*b*) flaccid leaves generally contain the parasite, in some cases, however, they are present only in small numbers, (*c*) sometimes loss of turgidity is not accompanied by the presence of *B. solanacearum*. Her interpretation of these results is that the invading organism did not cause the symptoms in a "direct way," which led her to include gum formation as a factor in the induction of wilting. It is not disputed that the conditions she lists do occur and in fact many similar conditions have been recorded, but all are readily explained without having to invoke any other factor than blocking by bacteria. By the stem sectioning or stem maceration analysis it has been demonstrated that the wilting of leaves in the presence of only small numbers of bacteria or no bacteria at all, is due to invasion lower down in the stem. In an earlier paper (Grieve, 1939) this point was stressed in relation to epinastic response of leaves. Turgidity of leaves in the presence of considerable though not "blocking" numbers of the invader is of common occurrence; epinasty of leaves which frequently precedes wilting, seldom occurs in the absence of the organism. Eosin conduction tests also showed that if even a few vessels remained uninvaded the dye passed upwards in them. It is considered that in the absence of complete section analyses of infected plant stems and roots, Van der Meer was led to an incorrect conclusion in the case of tomato plants. Certain of her own observations contradict her conclusions as she makes the following statements:—"The vessels containing the parasite remain *uncoloured* and the leaves or leaf parts obtaining water from these tracheae remained green," and "the experiments taught that the bacteria in the vessels form column-like masses which lengthen at both sides and branch when lateral ways (leaf petiole or lateral roots) make such possible."

A study of Smith's observations and illustrations (Smith, 1913, 1920), show that in the tomato and potato plants he studied, the invading organism was present in "blocking" numbers at the wilting phase. He, however, expressed no definite opinion as to the cause of wilting. Hutchinson (1913) sponsored the toxin theory of wilting in the case of tobacco plants and described an experiment which he considered proved that mechanical bacterial

blocking could not be responsible. He made a cut half way through the stem of a tobacco plant and inserted a thin strip of plasticene, believing that this would approximate to mechanical blocking in the vessels. No wilting occurred in the leaves above the cut and as he considered that the interference with water supply was greater here than in the case of a bacterially invaded stem, concluded that some other factor must cause wilting of the leaves. Hutchinson's experiment was repeated and others devised to check his interpretation. It was first shown that his expectation of wilting in leaves above a cut blocked with plasticene was not in accordance with water movement in the plant On placing a plant with its stem locally blocked in the manner he described and with its cut root in eosin solution, the dye passed up the uninterrupted bundles to the apex and then down the far side to the region blocked by the plasticene, passing into all the leaves on the way This indicated that the localized blocking had caused no real interference with the movement of water and made it clear why no wilting occurred

Critical experiments were next carried out to test under what conditions of artificial blocking, wilting of leaves in tomato and potato plants would occur The position of the vascular bundles in the stems of these plants is easily seen when they are placed in front of a bright light, and the procedure was adopted of cutting out very small pieces of the vascular bundles in the stem, just below or above a leaf, in order to interrupt the continuity of the water stream there Vaseline was used to block the cut regions Experimental results obtained were as follows —When one lateral bundle leading to a leaf was cut through and blocked, the leaf remained fresh; when a lateral and a central bundle were cut the leaf still remained fresh, but when in addition the terminal leaflet of the leaf being experimented with was removed, distinct unilateral flaccidity resulted The removal of the terminal leaflet when one lateral and the central bundle to the leaf are interrupted, prevents the return flow of water from the other uninjured lateral bundle Again, when in addition to the above treatments the vascular bundle leading to the next leaf above was cut, flaccidity became much more pronounced. On cutting all bundles leading up to a leaf together with the bundle leading to leaves higher on the stem, severe wilting of this leaf occurred in one hour. In certain experiments where only slight flaccidity of leaflets of a leaf occurred after cutting selected bundles, transport of dye showed that not all the vessels of the bundles had been cut and these few intact ones were transporting water. From this it was evident that even a few intact vessels could supply the necessary water to maintain a degree of turgidity in the leaf. The results of these experiments may be correlated with observations on actual occurrences in infected plants; thus the cutting of one lateral leaf bundle fails to induce wilting and is paralleled by the

fact that invasion of one lateral bundle fails to cause wilting, until bacteria in "blocking" numbers grow so far out in the lamina that water cannot be conducted back from the opposite side. Bacterial blocking of two laterals approximated to the cutting of two laterals and of the vascular bundle leading to the second leaf above The fact that a few intact vessels in a bundle could allow conduction of sufficient water to maintain turgidity in leaves, explains in large measure why leaves of infected plants can remain turgid so long when bacterial invasion is fairly heavy Not all vessels are blocked, except in the later stages of the disease and the few free vessels can pass sufficient water to keep the leaves reasonably fresh This turgidity of leaves is not to be confused, however, with the effect of the numbers of bacteria on the rate of transpiration The volume of water required to keep a leaf of tomato or potato plant turgid under average glasshouse conditions is relatively small (cf Knight, 1922), while as experiments on companion leaves proved, transpiration may be greatly reduced while leaves still appear quite fresh.

In dealing with the general subject of wilting in plants, Knight (1922) suggested that in the summer, due to a variety of factors, such as increase of atmospheric evaporating power and decrease in soil moisture, a greater tension was placed upon the water columns in the vessels leading to the gradual replacement of water by air, the water columns being severed one by one with the increasing tension until the number remaining unbroken could not supply the leaves with sufficient water to keep the plant alive The correctness of this conclusion was challenged by Bode (1923) who contended that even in the very last stages of wilting there were no air bubbles in the xylem

For a clearer understanding of the mechanism of wilting in infected plants these two viewpoints were tested.

Bode's technique was used to determine whether air bubbles developed in vascular bundles of tomato and potato plants showing (*a*) artificially induced wilting due to drying out of the soil, and (*b*) bacterially induced wilting. No bubbles were found in the vessels of tomato plants showing severe wilting due to drying out of the soil so that confirmation of Bode's work was obtained. The examination of bundles of infected plants to see the action of the bacteria proved somewhat more difficult as it was necessary to find the apices of the bacterial masses and to determine whether the water columns were intact above them The picture finally found was as follows:—Organisms at the head of the growing masses in the vessels were rapidly dividing and were actively motile The head of the bacterial column advanced due to packing of the organisms. No air bubbles were observed above the bacterial masses in individual vessels. Eosin dye failed to pass upwards through the bacterial mass, but after a longer period dye was observed coming downwards in the vessels above the

bacterial mass having first passed up the free vessels in other bundles This observation indicated the continuity of the water columns above the bacteria. As stated above no eosin passed from below through the bacterial mass, but the possibility remains that a very small but sufficient amount of water was passing between the packed bacteria to keep the water column intact, but this volume of water was quite insufficient to keep the leaves turgid. These experiments offer no confirmation of the view that actual rupturing of the water columns occurs, rather the reverse because if it were so the bacteria could not grow upward and downwards in the vessels

Bacterial action in the vessels may be pictured as follows.—The growing bacteria first fill one vessel and interrupt gradually the water flow in it until finally complete blocking occurs, then they spread to a second and repeat the process, and so on, finally few or no vessels in a bundle or bundles leading to one or more leaves are left uninvaded and blocked Wilting then occurs The process in the earlier stages is localized and the interruption of the water supply relatively slow Wilting gradually becomes systemic as the bacteria debouch into and block new vessel groups at the points of junction of bundles in the stem.

Summary.

1 The effect of *Bacterium solanacearum* on the water relations of tomato and potato plants has been analysed in relation to speed of invasion and the production of leaf epinasty and wilting

2 It has been shown that the march of transpiration in infected and control plants runs parallel until several leaves of the infected plants are showing epinasty and unilateral or bilateral wilting As increasing numbers of leaves are affected a gradual depression of transpiration rate occurs. The maintenance of a high rate of transpiration in infected plants despite a considerable reduction in effective leaf area in the earlier stages of wilting, was paralleled in experiments on healthy plants in which successive leaves were vaselined The significance of these results is discussed

3 The march of absorption in relation to invasion follows a closely similar path to that of transpiration under the same conditions Where the parasite was inoculated at the stem apex, no reduction in absorption occurred before the bacteria were present in "blocking" numbers in several root vessels after growing downward through the vessels of the stem

4 The transpiration and absorption experiments, together with eosin transport tests and histological studies, showed in the case of infected tomato and potato plants, that the wilting of leaves was due to gradual mechanical blocking of the vessels by the parasite and not to the presence of tyloses, gum or toxins

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Explanation of Plate.

PLATE XI.

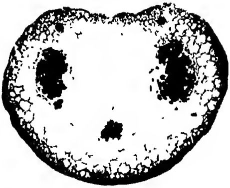
FIG 1—Leaf epinasty preceding bacterial wilting No obvious depression of transpiration is occurring at this phase Expt. 4

FIG. 2 Wilting due to bacterial invasion. This is the same plant as in Fig 1, photographed at the close of Expt 4

FIG 3.—Photograph of a transverse section at the base of a petiole of a wilted leaf. Note the complete blocking of vessels by bacteria. Breakdown of xylem is also occurring

1

2



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Art X.—The Genus Cycloclypeus in Victoria.

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Introduction.

The foraminiferal genus *Cycloclypeus* in Victoria, occurs within very restricted limits in the Batesfordian horizon of the Middle Miocene. The genus was first recognized in Victoria by F. Chapman, who, in 1910, recorded *Cycloclypeus pustulosus* Chapman (1905) in association with *Lepidocyclina* from the polyzoal limestone beds at Batesford near Geelong. In 1930 Chapman and the present author described *Cycloclypeus communis* Martin from the polyzoal limestones of Batesford and Le Grand's Quarry near Longford as well as from No 3 Bore, Parish of Darriman, no reference being made to the form previously recorded from Victoria by Chapman as *C pustulosus.* This latter species was described by Chapman from Wai Malikoliko, Santo, New Hebrides, from beds apparently of Lower Miocene age, whilst *C. communis* was originally described by Martin from Middle Miocene beds in Java

Cycloclypeus is found not only as a fossil but also living in recent seas, especially in the Indo-Pacific region Deposits of limestones composed almost entirely of tests of *Cycloclypeus* and of Miocene age, occur in North-West Australia, and in New Guinea, whilst a species is fairly common in the Upper and New Quarries at Batesford. The genus is comparatively rare in European fossiliferous deposits, and its only record of recent occurrence in that region is from the Adriatic Sea.

It is not intended in the paper to discuss in detail the morphology and anatomy of the genus. This has been done in some detail by Tan Sin Hok (1932) in his work "On the Genus *Cycloclypeus* Carpenter." In the present short account of *Cycloclypeus* in Victoria the specific determination is made on a study of the nepionic apparatus with some consideration of the external characters. All figured specimens are in the Commonwealth Palaeontological Collection at Canberra.

Systematic Study of the Genus Cycloclypeus.

The first worker to study the genus was Carpenter in 1856, who erected it on recent specimens collected "from a considerable depth of water off the coast of Borneo" His diagnosis of the genus, except for a few minor alterations, still holds good Tan (1932, p 15), gives a description of the genus based on Carpenter's specimens—"The *Cycloclypei* can be defined as follows: Shell flat, with or without umbo, with or without pillars, with or without annuli, with or without radial ribs Contour circular or stellate Consisting of one single layer of equatorial chambers, in both generations composed of a planispiral nepionic apparatus, surrounded by a neanic apparatus constituted of chambers in concentric arrangement Sidewalls perforated, without lateral chambers Marginal cord, septa and sidewalls with canal-system."

Martin, in 1880, was the first to observe the embryonic apparatus in megalospheric specimens

In 1900, Chapman, in his work on Funafuti, discovered the microspheric form of *Cycloclypeus* His comparison of this form with the structure of *Heterostegina* is still recognized Further researches have been carried out by Silvestri and Hofker, whilst Tan Sin Hok (1932) has made extensive investigations regarding both the microspheric and megalospheric forms throughout the Netherlands Indies Later still, in 1938, Cosijn made a "statistical study of the phylogeny" of the Cycloclypei from Spain

Both the microspheric and megalospheric generations are found in Victoria, the former being exceedingly rare. The terminology used in describing these forms is based on the works of Tan and Cosijn and is listed below

Megalospheric Form

Three distinct stages of growth are discernible in the development of a *Cycloclypeus* shell

1 *Protoconch or embryonic stage*—The protoconch consists of two chambers, a rounded central one known as the proloculum, and a kidney-shaped one (the second protoconchal chamber) which surrounds the proloculum These two chambers constitute the embryonic apparatus, and in the Victorian Cycloclypei they are comparatively small but uniform in size

2 *Nepionic stage*—(1) The nepionic apparatus is the series of spiral whorls which originate from the protoconch The chambers comprising this apparatus show two stages of growth. (*a*) The operculinoidal substage This is represented by a simple individual chamber, which envelopes one side of the protoconch. This feature is constant in the Victorian specimens. (*b*) The heterosteginoidal substage This is represented by the divided chambers which follow immediately on the operculinoidal chamber.

(ii) The primary septa or nepionic septa are long septa which run in a vertical direction in the shell, dividing the nepionic whorls into chambers known as primary or nepionic chambers.

(iii) The secondary septa are short septa dividing the nepionic chambers into oblong or rectangular chambers.

(iv) The marginal cord represents the limit of the heterosteginoidal substage.

3. *Neanic or Cyclic stage.*—The neanic stage follows after the development of the nepionic stage, commencing when the spiral or heterosteginoidal method of growth is replaced by the cyclic method, which continues throughout the growth of the shell. This is the true *Cycloclypeus* character

MICROSPHERIC FORM.

The microspheric generation is always much larger than the megalospheric form and frequently much less ornamented.

1. The proloculum consists of a single rounded chamber.

2. The nepionic stage consists of a number of small chambers arranged in a spiral.

(i) The operculinoidal substage consists of numerous undivided chambers, instead of one as in the megalospheric form. The microspheric generation in the sections of the few Victorian specimens available has ten chambers.

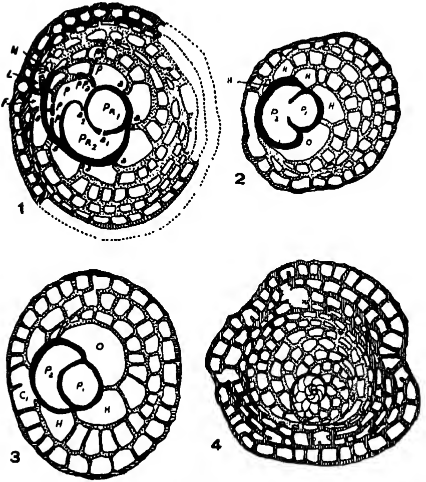
(ii) The heterosteginoidal substage consists of numerous divided chambers which number eighteen in the only satisfactory section of a Victorian specimen.

3. The neanic or cyclic stage is represented where the arrangement of the chambers passes from the spiral to the cyclic.

The structure of more than sixty horizontal sections of megalospheric specimens of *Cycloclypeus* from Victoria has been studied in this investigation, the number of specimens available being nearly four hundred, of these three hundred were from Batesford (one hundred from the New Quarry and two hundred from the Upper Quarry). Only six specimens were available from the Hamilton Bore, and more than one hundred from Gippsland, thirty being from Le Grand's Quarry, twenty from No. 6 Bore, Parish of Colquhoun (Lakes Entrance), and forty from No. 7 Bore. The number of microspheric specimens available was six.

Whilst the external characters show considerable variation, the study of the nepionic septa of numerous specimens leads to the conclusion that only one species is present. This form is being designated *Cycloclypeus victoriensis.* Variation in external sculpture is distinctive in different areas, although at times these variations tend to merge into one another. One variation is so persistent in the Gippsland region that it has been given varietal rank—*C. victoriensis* var. *gippslandica* nov. Tan's remarks on

this group of Cycloclypei (p. 62) might be quoted here: "The great variability of the sculpture of the megalospheric generation is not only shown by specimens of the same population, but also the specimens of separate populations show more or less marked constant differences. It appears that almost each locality yields its own phenotype."



FIGS 1, 2, 3, 4—Black, embryonic stage or pr [illegible] tched, neanic or cyclic stage Fig. 1 *Cycloclypeus indopacificus* (after Tan) PR_1 and [illegible] ers, a_1 and a_2 ap[illegible] assages through ne[illegible] septa; *a*, apertures, F, 1st chamberlet of 1st [illegible] ber, L, last chambe[illegible] of 1st neanic chamber, M, end of marginal cord. [illegible] C *indopacificus* (after Tan) and fig 3 C cf *guembelianus* (after Tan) P_1 and P_2, 1st and 2nd protoconchal chambers, O, operculinoidal substage, H, heterosteginoidal substage, C_1, regular neanic chambers Fig 4. Microspheric form (after Tan) nepionic stage with 21 chambers, 10 in operculinoidal substage and 11 in heterosteginoidal substage Chambers bounded by fine lines, nepionic stage.

The external features of the megalospheric generation of *Cycloclypeus* in Victoria are summarized as follows:—

(*a*) *Cycloclypeus victoriensis*, sp. nov., forma typica—Umbo distinct; pillars strong not only on umbo but on flange, where they are arranged concentrically and with rows fairly close together. Shell fairly thick. Specimens practically uniform in size. Diameter 6 mm. Typical of Batesford and Hamilton with a few specimens at Le Grand's Quarry, Gippsland. Pl. XII., fig. 1.

(*b*) *Cycloclypeus victoriensis* var. *gippslandica*, nov.—Umbo distinct, but not prominent; pillars fairly strong on umbo but finer on flange, where arranged concentrically, but with rows farther apart than in *C victoriensis*. Test thinner and frequently larger than in the type species. Diameter 2–8 mm Typical of the Gippsland bores and outcrops in the Glencoe-Stradbroke region, and in bores and outcrops east of Sale, rare at Batesford, absent at Hamilton. Pl. XIII., fig. 10.

Description of Species.

Family CAMERINIDAE

Genus Cycloclypeus Carpenter.

CYCLOCLYPEUS VICTORIENSIS, sp. nov.

(Pl. XII, figs 1-3, 5-8, Pl. XIII., figs 9, 17, Pl. XIV., figs 20-23, Pl. XV, figs 26-28, 31-32.)

Cycloclypeus pustulosus Chapman, 1910 (non 1905), p. 295, pl. lii., fig. 6; pl. lv., fig 4.

Cycloclypeus communis Chapman and Crespin, 1930 (non Martin 1880), p 112, pl. vii, figs. 7, 8, pl. viii, figs. 9-13.

Cycloclypeus pustulosus Tan, 1932, p. 84

Cycloclypeus communis Crespin (non Martin), 1936 (pars), p 7, pl. i, figs. 10, 11

Holotype—(A) Megalospheric Generation—Test circular in outline; umbo distinct, surrounded by a moderately thin flange. Slight annulus or fold immediately around umbo. Test covered with tubercules which are strong and irregularly arranged on umbo but in thirteen concentric rows on flange, which are fairly close together. The tubercules correspond with the annular divisions of the test. Towards marginal portion of test, they develop into radial ridges of varying length extending from the outside margin of each annulus towards periphery of preceding ring of chambers. Diameter 6 mm.; greatest thickness at umbo 1 mm.

The embryonic apparatus is represented by the protoconch which consists of two chambers, a central rounded one, the proloculum, and a kidney-shaped one partially surrounding the proloculum, the second protoconchal chamber. These chambers have a fairly thick shell wall (fig. 26). The embryonic stage is followed by the nepionic stage, the nepionic apparatus consisting

of almost a complete whorl containing ten septa including one operculinoidal and nine heterosteginoidal chambers. This stage is followed by the neanic or cyclic stage in which the majority of chambers are rectangular in shape. The marginal cord, a feature frequently difficult to secure in section, is present in figs. 26, 31, and is represented by a moderately thick wall

In vertical section, the side walls which lie on either side of the equatorial layer are not thick and are pierced by pillars, which are numerous in the type specimen.

Locality.—White limestone in New Quarry, Batesford, near Geelong at north end of tunnel (collected by F. A. Cudmore). Com. Pal. Coll. No. 157.

Paratypes.—(*a*) Le Grand's Quarry.—The external characters of this specimen are similar to the holotype, except that the edge of the test is smooth and rounded The nepionic septa are chiefly seven in number. The width of the test is 6 mm., which closely approximates the type.

(*b*) Hamilton Bore at 48–53 feet—The external features are similar to the holotype, the pillars appearing much stronger in the Hamilton form, due to the preservation of the shell. All the Hamilton specimens are strongly ironstained. A second specimen shows the pillars not quite so prominent, the test being rather smooth towards the margin. The width of both specimens is 5 mm. Horizontal sections were difficult to obtain owing to the mode of preservation.

Observations.—The Batesford specimens of *Cycloclypeus* were recorded by Chapman in 1910 as *C. pustulosus* Chapman (1905), and later by Chapman and Crespin (1930) as *C. communis* Martin, the previous reference as *C. pustulosus* being disregarded. In this latter paper, specimens were also figured from Le Grand's Quarry, Gippsland. No comparison has been made in the present paper with the megalospheric form of *C. pustulosus*, as specimens of that species were not available for this purpose. A horizontal section was not given by Chapman in the original paper, whilst the figure showing the external characters is in no way comparable with the Victorian forms. The Lepidocyclinae associated with *C. pustulosus* in the type locality indicate that this species belongs to a horizon older than that in which *C. victoriensis* is recorded. No specimens similar to that figured from the Batesford limestone could be found amongst the numerous examples examined during this investigation.

Tan (1932, p 84) in his remarks on *C. pustulosus* as figured by Chapman from the Batesford limestone, states that no specimen corresponding to Pl. 52, fig. 6 could be found in the Javan material. Unfortunately Tan had not seen the figure of the species from the type locality in the New Hebrides, but he does consider that Pl. 55, fig. 4 in the Batesford paper shows relationship with *C. indopacificus.*

As regards *C. communis* Martin, the average diameter of the megalospheric specimens of that form as given by Martin is 12 mm., with the microspheric (not recognized by Martin) up to 40 mm. These dimensions greatly exceed the two generations of the Victorian species. The arrangement of the nepionic septa in *C. victoriensis* is different from that shown by Martin in *C. communis*. In Chapman and Crespin's paper (1930), fig. 13 represents a section of a megalospheric specimen, not microspheric as stated. Douvillé's figures of *C. communis* (1909) from Madagascar show the test to be very closely ornamented with pustules. Tan takes this form (fig. 12) as his type for *C. indopacificus*.

The Victorian Cycloclypei are closely related to *C. indopacificus* of Tan. This authority has suggested that the Victorian form may be slightly more primitive than the Netherlands Indies form, this suggestion being based on the larger number of nepionic septa in the Victorian specimens. Tan considers that the greater the number of nepionic septa the more primitive or older the species, the fewer the septa the younger the form. Six nepionic septa are most frequent in *C. indopacificus*, with variation from four to six, whilst in its variations they range from four to seven, rarely eight. In *C. victoriensis*, the most frequent number is from seven to nine, with three specimens showing ten and one showing thirteen (Pl. XV, fig. 28). In the specimens from the Upper Quarry, Batesford, nine septa are most frequent, whilst in the Batesford New Quarry they number seven, and from Le Grand's Quarry seven.

In studying the populations in a particular locality and bed, certain variations are noticeable. In the Upper Quarry at Batesford where the specimens are numerous, the tests of *C. victoriensis* are uniform in size, being circ. 5 mm. in diameter. Here the type specimen is associated with a comparatively smooth form with a diameter of 3 to 5 mm., whilst the microspheric generation is also represented. The number of nepionic septa varies from seven to ten, with nine the most frequent. In the section in the New Quarry, the diameter of the tests of *C. victoriensis* forma typica, varies from 4 to 8 mm., with the average 6 mm. The number of nepionic septa varies from seven to ten with nine the most frequent. In this section the smooth form and the microspheric generation are absent, but a variety, *C. victoriensis* var. *gippslandica*, is sparingly present.

Very few specimens are available from the Hamilton Bore, these being recorded between the depths of 36 to 38 feet and 48 to 80 feet. All the tests measure 5 mm. and are strongly iron-stained, the internal structure being usually masked by glauconite replacement.

In Gippsland *C. victoriensis* is recorded from Le Grand's Quarry near Longford, where it is fairly common, the average

diameter being 5 mm. The nepionic septa number seven. It is associated with *C. victoriensis* var. *gippslandica, C. victoriensis* forma typica occurs only in two borings throughout Gippsland.

Occurrence.—*C. victoriensis* has been recorded from the following outcrops and borings in Victoria, where it is always associated with *Lepidocyclina.*

Outcrops: (i) Port Phillip Region.—Upper Quarry (Australian Portland Cement Co.), Batesford, near Geelong (Forms A and B), (coll. F. A. Singleton); New Quarry, Batesford, at N. end of tunnel (coll. F. A. Cudmore); Flinders (Forms A and B) (coll. I.C.).

(ii) Gippsland Region.—Le Grand's Quarry, south of Longford, Allot. 13, Parish of Glencoe (Forms A and B) (coll. I.C. and Victorian Mines Department).

Borings: (i) Western Victoria.—No. 1 Government Bore, Hamilton, Parish of Yulecart (4 chains south from bridge over Muddy Creek) at 36-38 feet and 48 to 80 feet.

(ii) Gippsland Region.—No. 14 Bore, Parish of Stradbroke at 705 feet, and No. 1 Bore, Parish of Nindoo at 190 feet.

(B) Microspheric Generation (figs. 6, 23).—(*a*) Batesford specimen—Test large, rather thick, about twice the size of the megalospheric form, measuring about 10 mm. (Complete specimens not available). Umbo district. Test faintly ornamented with pillars, irregularly arranged on umbo, concentrically on flange.

The embryonic stage consists of a protoconch, represented by small, rounded, single chambers. This is followed by a spiral (nepionic) apparatus consisting of twenty-eight chambers (nepionic septa). The operculinoidal substage which immediately follows the embryonic stage contains ten undivided chambers, which are followed by eighteen divided chambers constituting the heterosteginoidal substage The neanic stage with its cyclic arrangement of chambers immediately follows until the margin of the shell is reached. The chambers in the neanic stage almost quadrate in shape when immediately surrounding nepionic stage, then gradually becoming more and more elongated towards margin of shell.

(*b*) Flinders specimen—Test large, moderately thick, ornamented with fine pillars arranged concentrically on flange. Umbo distinct, represented by swelling towards centre of shell. Diameter—circ. 10 mm.

Observations.—It is unfortunate that specimens of the microspheric form are so rare. As a result of this scarcity the description of the internal characters has been based on one specimen but Tan has shown that the characters of the embryonic and nepionic chambers in the microspheric form are fairly constant. Only three specimens were available from Batesford, all from the Upper Quarry section. One example was available from Flinders, while no specimen was found in the Hamilton Bore.

Occurrence.—Upper Quarry, Batesford, near Geelong (figured specimen of exterior pres. W. J. Parr; sectioned specimen, coll. F. A. Singleton); and Flinders.

Age.—Middle Miocene (Batesfordian).—The stratigraphical horizon is fairly high in the Middle Miocene, and the equivalent of *f 2* stage in the Netherlands Indies, New Guinea, Papua and North-West Australia. This stage probably correlates with the upper portion of the Burdigalian of Europe. The *C. indopacificus* type of nepionic septa is characteristic of this horizon.

CYCLOCLYPEUS VICTORIENSIS var. GIPPSLANDICA, nov.

(Pl. XII, fig. 4; Pl. XIII., figs. 10-16, 18; Pl. XIV., figs. 19, 24, 25, 29, 30.)

Cycloclypeus communis Crespin non Martin, 1936 (pars), p. 7.

Holotype of variety.—(A) Megalospheric Generation.—Specimen incomplete. Umbo distinct, pillars fairly strong on umbo but finer on flange, where arranged in seventeen concentric rows which are farther apart than in *C. victoriensis*. Test larger than in type. Diameter 8 mm.

Embryonic apparatus as in type. Nepionic septa—six. Chambers in the neanic stage tend to become elongated towards margin.

Locality.—No. 5 Bore, Parish of Glencoe at 50 feet. (Com. Pal. Coll No 163.)

Paratypes —(*a*) Parish of Darriman, No. 3 Bore at 439 feet. Test similar to type. Diameter 7 mm.

(*b*) Parish of Nindoo, No. 1 Bore at 190 feet. Umbo less prominent than in (*a*). Test thin and rather wavy. Diameter 6 mm

(*c*) Skinner's section, Parish of Wuk Wuk, Mitchell River. Umbo not prominent, pillars developing into ridges towards margin of shell. Specimens translucent. Diameter 6 mm.

(*d*) Parish of Colquhoun, No. 7 Bore, 620 feet. Test fairly smooth with pillars scattered irregularly over surface. Umbo indistinct, represented by gradual thickening of side walls towards centre of shell. Nepionic septa, eight. Diameter 4 mm.

Observations.—*C. victoriensis* var. *gippslandica* is found in association with the "forma typica" in Gippsland in Le Grand's Quarry, and in No. 1 Bore, Parish of Nindoo at 190 feet. In no locality was a complete specimen available so dimensions are only approximate.

The main distinction between the two forms lies in the larger size and different and finer ornamentations of the variety. The nepionic septa range from six to eight with six the most frequent. There is also some variation in size and ornament in different populations. At Le Grand's Quarry, except for the presence of

the type species, the majority of the specimens are typical of the type of the variety. In No. 1 Bore, Parish of Nindoo at 190 feet, specimens are comparatively common and some variety in ornamentation and stages of growth is illustrated. The limbation of the outer chambers is very strong, being both radial and concentric. The shell surface is rectangularly reticulated. The dimensions range from 1 mm. up to 8 mm. The shell has not grown beyond the heterosteginoidal stage in the smallest specimens, the surface of the test being smooth and transparent in some and strongly beaded in others In some of the larger specimens the pillars are so developed as to form strong ridges between the septa. The examples from Skinner's section along the Mitchell River, about 10 miles to the north-east of the Nindoo Bore, show similar characteristics.

C. victoriensis var *gippslandica* is well represented in the Lakes Entrance (Parish of Colquhoun) bores, specimens varying from 2 to 6 mm. in diameter. The nepionic septa number from six in No. 4 Bore (Pilot Station) to eight in No. 7 Bore (Lake Bunga). Tests are usually rather worn and broken, but in No 8 Bore (North Arm) they are well preserved and very common Unfortunately these specimens were not available for inclusion at the time when the plates were assembled

Occurrence—Outcrops: (i) Port Phillip Region.—Batesford at top of the New Quarry at the north end of the tunnel (rare).

(ii) Gippsland Region—Le Grand's and Brock's Quarries south of Longford, Parish of Glencoe (Forms A and B); along the Mitchell River, at Skinner's section, Parish of Wuk Wuk; and north cliff, east of Hillside Bridge, Parish of Wy Yung.

Borings: Gippsland Region.—Parish of Glencoe, No. 5, 50 feet, Parish of Glencoe South, Tanjil-Pt. Addis No. 2 Bore, 560-650 feet, Texland Bore, 330 feet; Parish of Stradbroke, No. 14 Bore, 745 feet; in No. 16 Bore, 610 feet; Parish of Darriman, No. 3 Bore, 379 and 439 feet; Parish of Dulungalong, Signal Hill Bore, 1,573 feet; Parish of Nindoo, No. 1 Bore, 190 feet; Parish of Coongulmerang Steam Drill, 914-916 feet; Parish of Colquhoun, No. 3 Bore (Nungurner), 891 and 893 feet; in No. 4 Bore (Pilot Station), 855 and 860 feet; No. 6 Bore at 887 feet, No. 7 Bore at 620 feet and No. 8 Bore between 565 feet and 590 feet.

(B) Microspheric Generation.—(*a*) Le Grand's Quarry, south of Longford—Test large, thin, almost smooth but faint pillars are present arranged concentrically on flange. Umbo indistinct. Diameter 12 mm.

The heterosteginoidal chambers are visible but most of the central portion has been altered. In the neanic or cyclic stage, the chambers are elongated rectangular and are fairly close together, this attenuation becoming very pronounced towards margin of shell.

(*b*) Brock's Quarry, south of Longford.—Test large, thin, with uneven surface which is ornamented with faint pillars arranged fairly closely together and concentrically on flange. Twenty-six annuli, visible and irregularly arranged, becoming farther apart as margin of shell is reached, indicating the narrow, elongated chambers shown in horizontal section. Diameter 16 mm.

Observations.—The arrangement of the pillars on the surface of the test and the elongated rectangular shape of the chambers, as shown in horizontal section, leaves little doubt that these specimens from Gippsland represent the microspheric generation of *C. victoriensis* var *gippslandica*. They are also larger than the microspheric forms of *C. victoriensis* from Batesford and Flinders. At the same time, the microspheric specimens of both *C. victoriensis* and *C victoriensis* var. *gippslandica* are proportionally larger than the megalospheric ones. As with *C. victoriensis*, specimens available for examination were few Two were present in the material from Le Grand's Quarry and one each from Brock's Quarry and No. 1 Bore, Parish of Nindoo.

Occurrence.—Gippsland Region.—Le Grand's Quarry and Brock's Quarry, south of Longford in the Parish of Glencoe; No. 1 Bore, Parish of Nindoo at 190 feet.

Age.—Middle Miocene (Batesfordian).

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Explanation of Plates.

Cycloclypeus victoriensis, sp nov.

Plate XII.

Fig. 1.—*Cycloclypeus victoriensis*, sp. nov. N. end of tunnel, New Quarry, Batesford. Exterior of test of Megalospheric specimen. Holotype. No. 157. × 8.

Fig 2.—Upper Quarry, Batesford. Megalospheric. Paratype. No. 158. × 9.

Fig. 3.—N. end of tunnel, New Quarry, Batesford. Megalospheric. Paratype. No. 159. × circ. 9.

Fig. 4.—Var. *gippslandica* nov. New Quarry, Batesford. Megalospheric. Paratype. No. 160 × 9.

Fig 5—*C. victoriensis*, sp nov. Upper Quarry, Batesford. Megalospheric. Smooth specimen. Paratype. No. 161. × 8.

Fig. 6.—Upper Quarry, Batesford. Exterior of portion of microspheric specimen. No. 184. × circ. 6.

Fig. 7.—No. 1 Government Bore, Hamilton, Parish of Yulecart, at 48–53 feet, specimen ironstained. Megalospheric. Paratype. No. 162. × circ. 8 5.

Fig 8.—Locality similar to Fig. 7. Specimen ironstained. Paratype, No. 83 × circ. 10.

Plate XIII.

Fig. 9.—*C victoriensis*, sp nov. Le Grand's Quarry, near Longford. Parish of Glencoe, Gippsland. Megalospheric. Paratype. No. 7. × circ. 8.

Fig. 10.—Var. *gippslandica* nov. No. 5 Bore, Parish of Glencoe, 50 feet. Megalospheric. Holotype of var. No. 163. × circ. 7.

Fig. 11.—Var. *gippslandica* nov. Le Grand's Quarry, near Longford, Parish of Glencoe. Megalospheric. Paratype. No. 164 × 9.

Fig. 12.—Var. *gippslandica* nov. No. 5 Bore, Parish of Glencoe, 50 feet Megalospheric. Paratype. No. 165. × circ. 8.

Fig. 13.—Var. *gippslandica* nov, No. 1 Bore, Parish of Nindoo, Gippsland, at 190 feet. Megalospheric. Paratype. No. 166. × 9.

Fig. 14.—Var. *gippslandica* nov. No. 7 Bore, Parish of Colquhoun (Lake Bunga), Gippsland Lakes, at 620 feet. Small specimen typical of area. Paratype. No. 167. × 8.

Fig. 15.—Var. *gippslandica* nov. Skinner's section, Mitchell River, Parish of Wuk Wuk (near Bairnsdale). Megalospheric specimen showing regeneration of test. Paratype. No 168 × 10.

Fig 16.—Var. *gippslandica* nov. No. 3 Bore, Parish of Darriman, Gippsland, at 439 feet. Paratype. No. 169. × circ. 9

Fig. 17.—*C victoriensis*, sp. nov. No. 1 Bore, Parish of Nindoo, Gippsland, at 190 feet. Megalospheric, small specimen. Paratype. No. 170 × circ. 8

Fig 18.—Var. *gippslandica* nov. Skinner's section, Mitchell River, Parish of Wuk Wuk (near Bairnsdale). Megalospheric. Specimen showing fairly well marked annuli Paratype. No. 171. × circ. 9.

Plate XIV.

Fig. 19.—Var *gippslandica* nov. No. 4 Bore, Parish of Colquhoun (Pilot Station). Horizontal section showing seven large nepionic septa. Annuli in neanic stage irregular. Megalospheric Tectotype No. 172. × 20.

Fig 20—*C. victoriensis*, sp. nov New Quarry, Batesford Horizontal section of megalospheric specimen similar to external of Holotype, showing two protoconchal chambers, ten nepionic septa including one operculinoidal and nine heterosteginoidal chambers. Chambers in neanic or cyclic stage show regeneration. Tectotype. No. 172. × 20.

Fig. 21.—New Quarry, Batesford. Section slightly eccentric. Eight nepionic septa visible. Operculinoidal chamber indistinct. Neanic stage fairly regular. Megalospheric. Tectotype. No. 173 × 20.

Fig. 22.—Upper Quarry, Batesford. Ventral section of megalospheric form showing lateral chambers. Tectotype. No. 174. × 20.

Fig. 23.—Upper Quarry, Batesford. Microspheric specimen, showing elongated character of chamber towards margin of test. Tectotype. No. 175. × 12.

Fig. 24.—Var. *gippslandica* nov. No. 5 Bore, Parish of Glencoe, Gippsland, at 50 feet. Megalospheric. Embryonic apparatus abnormal. Five nepionic septa visible. Neanic or cyclic stage regular. Centre of test partially replaced by glauconite Tectotype. No. 176. × 12.

Plate XV.

Fig. 25.—Var. *gippslandica* nov. No 6 Bore, Parish of Colquhoun, Gippsland, at 887 feet. Sections showing nine large nepionic septa Arrangement of chambers regular around nepionic apparatus. Tectotype No. 177. × 20.

Fig. 26.—*C victoriensis*, sp nov New Quarry, Batesford. Enlargement of embryonic and nepionic apparatus of Fig 20. Marginal cord distinct Tectotype No. 172 × 40

Fig. 27.—Upper Quarry, Batesford. Section showing eight nepionic septa, including one operculinoidal chamber and seven heterosteginoidal. Tectotype. No. 179. × 60.

Fig. 28.—Upper Quarry, Batesford Section showing thirteen nepionic septa (one operculinoidal and twelve heterosteginoidal). Tectotype No. 180. × 33

Fig. 29.—Var. *gippslandica* nov No 6 Bore, Parish of Woodside, Gippsland. Centre of test filled with glauconite. Two protoconchal chambers of embryonic apparatus unusually large and thick-walled Marginal cord distinct. Tectotype. No. 181. × 60.

Fig 30.—Var *gippslandica* nov. Le Grand's Quarry, near Longford, Parish of Glencoe. Section showing seven nepionic septa Tectotype. No 182. × 60.

Fig 31.—*C victoriensis*, sp nov New Quarry, Batesford Section slightly oblique Seven nepionic septa visible. Wall of embryonic apparatus thick Marginal cord distinct. Tectotype. No 183. × 60

Fig 32—Upper Quarry, Batesford. Microspheric, specimen showing one protoconchal chamber, ten operculinoidal and eighteen heterosteginoidal chambers. Tectotype No 178. × 60

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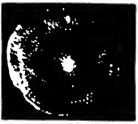

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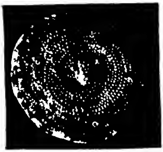
Cycloclypeus from Victoria.

1029/41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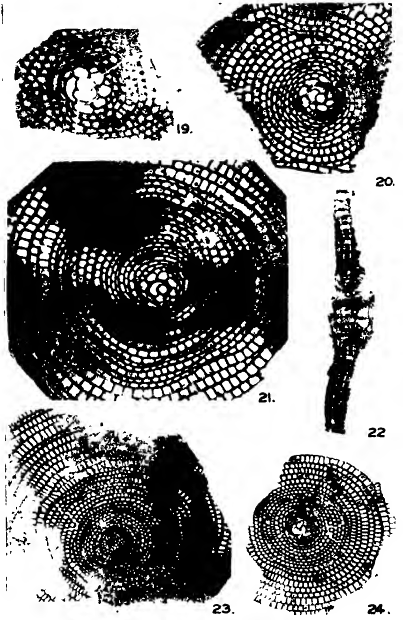
Cycloclypeus from Victoria.



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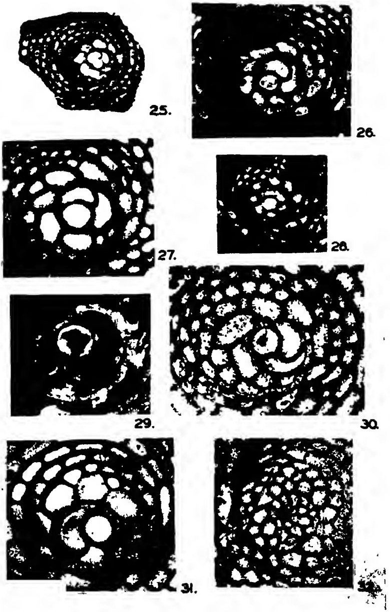

Cycloclypeus from Victoria.

[Proc. Roy. Soc. Victoria, 53 (N.S.), Pt. II., 1941.]

Art. XI.—*Studies in the Physiology of Host-Parasite Relations.*

II. Adventitious Root Formation.

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Introduction.

Recent advances in the study of the response of healthy plants to growth substances have suggested the possibility of their being concerned in similar stimulation effects induced in plants infected by certain bacterial pathogens.

Three pathogenic organisms which induce atypical growth response in some host plants are *Bacterium solanacearum* (Bacterial Wilt of Solanaceae), *Aplanobacter michiganense* (Bacterial Canker of Tomato) and *Bacterium tumefaciens* (Crown Gall).

The production of adventitious roots on intact stems of tomato is induced by all three organisms, epinasty of leaves and stimulated cambial activity are induced by *B. solanacearum* and *B. tumefaciens,* while cell proliferation leading to gall formation is characteristic of *B. tumefaciens.*

In an earlier paper (Grieve, 1939) the epinastic response of leaves, induced by *B. solanacearum,* was examined and the question of its proximal cause discussed. Epinastic response of leaves, adventitious root formation and cambial stimulation induced in plants by *B. tumefaciens* and the relations of these effects to growth substance has been studied by Locke, Riker, and Duggar (1938). The present paper deals firstly with observations on the development of adventitious roots in plants invaded by *Bacterium solanacearum* and secondly with their relation to growth substance, comparisons being made with similar effects induced by humidity, gravity, wounding, blocking, synthetic growth substances and by the two other organisms referred to above.

That tomato plants react to invasion by *B. solanacearum* by the formation of adventitious roots was first indicated by Hunger in 1901. His observations were confirmed by Smith (1914, 1920) who demonstrated that adventitious roots arose above and below the point of inoculation whereas no adventitious roots developed on control stems pricked with a sterile needle. Smith also

demonstrated that adventitious roots developed on infected tobacco stems. Bryan (1915) while working with tall and dwarf varieties of garden nasturtium (*Tropaeolum majus*) observed that the tall varieties reacted to bacterial invasion by adventitious root formation.

Hutchinson (1913) and Smith (1920) made tentative suggestions as to the proximal cause of this stimulation effect but no critical investigation appears to have been attempted.

The present work was commenced when the characteristic development of the roots was observed in artificially infected tomato plants (Grieve, 1936A).

Methods.

In the case of *Bacterium solanacearum* the technique of inoculation, the cultures used and the methods of fixing and staining infected material were as described in an earlier paper (Grieve, 1939) The culture of *Aplanobacter michiganense* used was a strain isolated from tomato in Victoria by A Pugsley of the Department of Agriculture, and the Crown Gall organism was a strain isolated from almond (Grieve, 1934).

Test plants were grown in a glasshouse during spring and summer months, minimum night temperatures being approximately 58°F. and average day temperatures ranging from 65°F. to 80°F. The following plants were examined for adventitious root formation after infection by *Bacterium solanacearum:*—*Lycopersicum esculentum* Mill., *Solanum tuberosum* L., *Solanum nigrum* L., *Solanum dulcamara* L., *Tagetes erecta* L., *Helianthus annuus* L., *Tropaeolum majus* L., *Ricinus communis* L., and *Impatiens balsamina* L.

After determining experimentally which plants showed the reaction, further experiments were made with those in which it developed most conspicuously. Tomato plants only were used for observing stimulation effects due to *Bacterium tumefaciens* and *Aplanobacter michiganense.*

For observations on the outgrowth of adventitious roots under humid conditions the plants were placed under bell jars or in large glass cases.

To ascertain the effect of gravity on adventitious root formation in tomato, experiments were performed in which some plants were staked horizontal and others rotated on a klinostat in order to neutralize the effect of gravity. All these plants were kept under humid conditions.

Experiments to determine the concentration of β-indole-acetic acid necessary to cause approximately equivalent adventitious root formation on tomato and other plants were made using water

solutions contained in small glass tubes drawn to a capillary at one end. The capillary end of the tube was inserted into the stem in the vicinity of a vascular bundle and its contents allowed to drain slowly into the plant. Each tube had a capacity of about 0.4 cc. and the concentration was 0.03 per cent. Lanoline-water emulsions of β-indole-acetic acid were used in some of the experiments relating to the effect of gravity and of growth substance on adventitious root formation.

The presence of growth substances in liquid media in which cultures of the organisms named earlier had been grown (for composition of media used see Grieve, 1939) was detected using the ether extraction procedure of Thimann and Bonner (1933) with *Avena* coleoptile tests. The *Avena* tests were made according to Went's technique (1928) and "Victory" oats were used. The husked oats were soaked for two hours, then the water was poured off and they were left in light for a further seven hours. They were then transferred to petri dishes lined with moist filter paper and germination allowed to proceed for about 30 hours. By this time the coleoptiles and roots were well developed and the seedlings were planted in individual holders with their roots in water and grown in a compartment held at 25°C. and 90 per cent, relative humidity. When the coleoptiles had reached a length of approximately 3 cm. they were ready for use and the standard method of decapitation and application of the agar blocks mixed with extracted growth substance was followed. Dolk and Thimann's method (1932) of preparation of agar blocks mixed with extracted growth substance was used, the final volume of each block for application to a decapitated coleoptile being 10.7 cmm.

For comparing growth substance content of stem parts of inoculated and healthy tomato plants the diffusion method was first tried, in which comparable stem parts from test and control plants were placed on agar plates of a size $8 \times 10.7 \times 1.5$ mm. for two hours. Each agar plate was then cut into twelve small blocks of equal size and these applied to decapitated coleoptiles. Satisfactory results for tomato were only obtained, however, when stem portions close to the apex were used. Overbeek's ether extraction method (1938) was next tried and as more satisfactory results were obtained it was used for most of the experiments. In comparing the growth substance content of the plants, equal fresh weights of stem parts were extracted separately.

The experiments on mechanical blocking of bundles were made using cocoa butter, lanoline and a paraffin wax-vaseline mixture. The blocking substances were introduced in the melted state through incisions in the plant stems.

Observations on Adventitious Roots in Healthy Plants.

Adventitious roots may be defined as those which arise in unaccustomed places and for the purposes of this paper are limited to those which develop on the stems of intact plants. In origin they are endogenous, developing by the formation of apical root meristems from the pericyclic regions in the vicinity of the outer phloem groups. Owing to the fact that these adventitious roots sometimes develop on healthy plants, a study was first made of some of the determining factors. Observations extending over fortnightly periods, were made on batches of tomato, sunflower, garden nasturtium, balsam, black nightshade, African marigold and potato plants of varying ages which were growing quite straight in the glasshouse. Only a very sparse development of adventive root primordia was observed in tomato, African marigold and balsam plants and none in the other plants.

The adventitious roots visible at the surface as small nodular projections covered by the epidermis, were confined to the basal internodes in tomato and to 1 to 2 inches above soil level in African marigold. The plants were next grown for fourteen days in highly humid conditions under bell jars and glass cases. Only a slight increase in the number of root primordia was observed. Very rarely did these root anlage pierce the epidermis and grow out into the humid atmosphere It has frequently been observed in tomato plants which bend over sideways (often as a result of watering) that adventitious root primordia develop in some abundance along the lower side of the stem. This suggested that gravity was an important factor and experiments extending over fourteen days were performed in which stems of tomato plants were staked horizontally, both under normal and under very humid conditions. Root primordia developed on the lower side of the stems over several internodes up to the point where the unstaked tips turned upwards. This observation confirmed that made earlier by Laibach and Fischnich (1935), but the experiment was next carried further by rotating tomato plants with their stems held in a horizontal position on a klinostat for ten to fourteen days. No trace of adventitious root formation, even under very humid conditions occurred over the length of such horizontally rotated stems. These experiments made it clear that gravity and not humidity was the dominant causal factor in adventitious root formation in tomato. The development of these roots on the lower side of the horizontally staked stems where gravity is exerting its effect, was suggested by Laibach and Fischnich (1935) to be due to some movement of root forming substance from the upper to the lower side. In the experiments where the plants were rotated on the klinostat, each side of the stem was successively subjected to the influence of gravity and it is suggested that under these conditions no such localized accumulation of root forming substance can occur and no adventitious roots develop. Support for this view was given by

further experiments in which β-indole-acetic acid in lanoline was smeared for 1 inch along the upper surfaces of plant stems staked horizontally and for a comparable distance along one side of stems of plants ready for rotation on the klinostat. In the former case, root primordia developed over the upper treated region as well as along the lower surface, while in the rotated stems root primordia developed only along the line of growth substance smear. It was observed, even in the plants staked horizontally under humid conditions and where numerous root primordia became visible at the surface, that these only occasionally broke through the epidermis and grew out into the moist air. When such stems were staked horizontally in contact with moist soil or moss, however, the adventitious roots grew out speedily. These results suggest that contact stimulus is important in relation to the outgrowth of the roots which develop in response to gravity effect. It should be noted that this contact stimulus is not necessary for the outgrowth into humid air of adventitious roots when these are induced by growth substances or by bacterial infection.

Having defined the conditions and degrees of development of naturally forming adventitious roots in test plants, attention was next directed to ascertaining those host plants in which bacterial infection by *Bacterium solanacearum* stimulated definite root formation.

Range of Host Plants which Develop Adventitious Roots.

The pathogen *B. solanacearum* was inoculated either at the apex or base of the stems of test plants. Control plants were pricked in the same regions with a sterile needle to serve as a check on normal adventitious root formation Conditions in the glasshouse were such that the air in the vicinity of the plants was humid but no attempt was made to place the plants under very humid conditions. Results are expressed in Table I.

TABLE I.—TEST FOR ADVENTITIOUS ROOT FORMATION IN PLANTS INFECTED BY *B. solanacearum*

Test Plant	Result
Lycopersicum esculentum—	
var Marglobe	+ + +
„ Burwood Wonder	+ +
„ Dwarf Champion	+
Tropaeolum majus—	
Tall variety	+ +
Dwarf variety	+
Tagetes erecta	+ +
Helianthus annuus	+
Solanum nigrum	—
„ *dulcamara*	—
„ *tuberosum*	—
Ricinus communis	—
Impatiens balsamina	—

+ + + signifies a large number of induced roots. — signifies no roots

The tomato variety Marglobe consistently showed the greatest number of adventitious roots developing, both above and below the inoculation point, and was consequently used as the main test variety for the experiments to be described later. The observations of Bryan (1915) regarding adventitious root formation on infected tall varieties of *Tropaeolum majus* were confirmed and it was also demonstrated that under the conditions of slow invasion in some of these experiments adventitious root formation could occur in dwarf varieties. The records of root formation on *Tagetes erecta* and *Helianthus annuus* are new. The effect was so definite in the former case that this plant was selected for additional experiments. Considerable difficulty was experienced in obtaining successful inoculations on sunflower plants, but in those cases where the disease occurred root primordia were found developing along the invaded bundles. Control plants pricked with a sterile needle showed a complete absence of such root primordia. No confirmation was obtained for the report by Stanford and Wolf (1917) that *Impatiens balsamina* reacted to invasion by adventitious root formation. The inoculation points were 1½ to 2 inches above soil level and no roots developed above this level. The occasional development of roots, at or about soil level, was found to occur both in infected and healthy plants when held under humid conditions. Infected balsam plants showed marked browning of vessels (visible externally) due to gum formation, this being followed by wilting of leaves. Plants of *Solanum nigrum* and *Solanum dulcamara* wilted without development of roots, even when placed under conditions favouring slow invasion. Infected potato plants showed the stimulation response of leaf epinasty but no trace of adventitious root formation on the stem was observed.

Considerable variation, even between plants of closely similar size and vigour, was found in the period for the development of bacterially induced roots to the stage where they were clearly recognizable at the surface. This variation is probably due to the more rapid growth of the pathogen in one plant than another owing to more favourable implanting.

For tomato the minimum time for the adventitious roots to show as nodular swellings under the epidermis was found to be four days. This was recorded from three Marglobe tomato plants growing under conditions suitable for fairly rapid invasion. The majority of records, however, showed that six to ten days elapsed after inoculation before the roots were clearly distinguishable. Longer periods, extending from 14 up to 28 days, were recorded under conditions of slow invasion during autumn months. Under environmental conditions which favoured rapid invasion wilting occurred in tomato plants (6 to 8 inches tall) without any sign of root formation. Sections of stems of such plants failed to show any indication of the start of root primordia. Younger

tomato plants (3 to 4 inches tall) wilted without developing adventive roots even when invasion was retarded. Under optimum conditions invasion progressed more slowly in African marigold than in tomato, the minimum time recorded for root development to the nodule stage was fifteen days. The average time was 26 to 30 days. The invading bacteria were seldom present in the stem vessels in "blocking" numbers as in tomato and their rate of movement in the stem was much slower. The adventitious roots which developed were quite comparable in numbers to those on tomato plants.

REGIONS OF DEVELOPMENT OF ADVENTITIOUS ROOTS.

In naturally infected tomato plants adventitious roots developed characteristically along the path of the primary bundles, spreading later to the secondary tissues. Under conditions of moderately rapid invasion in plants 8 to 10 inches tall (wilting commencing in 12 to 15 days), adventitious roots were observed over as many as seven or eight internodal regions. They did not commonly develop in apical regions. Artificial inoculations by needle prick were generally made in the vicinity of the primary bundles. Definite root formation occurred both above and below the prick as the bacteria multiplied and the bacterial columns spread upwards and downwards in the vessels. Hunger (1901) observed that adventitious roots developed on tomato leaf petioles as well as on the stem. In the course of this investigation, however, none has been seen to develop on leaf petioles.

The root primordia which developed were very variable in number on different tomato plants. The average number was between 40 and 50, extending over four to five internodes, with maximum numbers of roots ranging up to 200. On the other hand as few as five to six primordia definitely associated with the disease were recorded. In control plants as many as five to six naturally occurring roots were recorded in basal internodal regions.

For African marigold and garden nasturtium the development of the induced roots was along the course of the bundles and the numbers developing were comparable in any internode to those on tomato. In sunflower the numbers of induced roots were few.

THE EFFECT OF HUMIDITY ON THE OUTGROWTH OF BACTERIALLY INDUCED ROOTS.

Under normal glasshouse conditions the individual roots develop no further than nodular projections covered by the epidermis, but when test plants are placed under humid conditions in glass cases or under large bell jars a large proportion, but not all, of the nodules force their way through the epidermis and grow out into the humid atmosphere. The length to which these roots grow out varies from ½ inch to 2 inches. It was noticeable that

the greatest tendency for strong outgrowth of roots was in the lower internodes, but outgrowth from apical internodes was also recorded (Pl XVI., fig 1) Examination of Pl XVI, figs 1, 2 and 4, show that both in tomato and African marigold a number of the nodules fail to grow out Sections through these have shown the presence of bacteria in large numbers in the vessels behind the root primordium After some days the tips of several of the roots which grew out showed browning and no further growth occurred Quite a long period elapsed however before any further breakdown changes were observed, even though test plants were in many cases badly infected and showing bacterial ooze at the surface of the stem

In other experiments stems of infected plants were cut near the base and placed in a beaker of water under a bell jar. A much higher proportion of the nodules broke through the epidermis and grew out into the humid air (Pl XVI., figs 1 and 4) This increased outgrowth as compared to that on intact plants may be due, at least in part, to the diffusion of the "blocking" bacteria from the vessels allowing the transport of more water to the root primordia As indicated earlier, intact healthy plants held under humid conditions have only rarely shown outgrowth of adventitious roots and these also were confined to the basal internodes. When cut stems of such plants were placed in water, roots developed in considerable numbers below the water surface. This contrasted strikingly with the appearance of infected plants, where the adventitious roots developed conspicuously on the stem both above and below the surface of the water

Comparison of Adventitious Root Formation by *B. solanacearum*, *B. tumefaciens* and *A. michiganense*.

Adventitious root formation in tomato plants inoculated with *B tumefaciens* did not compare in numbers, or in longitudinal distribution on the stem, with those induced in similar plants infected with *B. solanacearum* Even when inoculations were made at five or six points on the stem as Locke, Riker and Duggar (1938) recommended, the numbers of roots, which were closely associated with the galls, did not approach in numbers those induced by the bacterial wilt organism. This difference in numbers and distribution is of course related to the rather localized nature of invasion in Crown Gall, as against the systematic development in bacterial wilt of Solanaceae. When placed in a humid atmosphere, outgrowth of the root nodules occurs in the same manner as do those in plants infected with *B. solanacearum* but no browning and breakdown of the outgrown roots was seen to occur in Crown Gall. No evidence has so far been presented to show that *B. tumefaciens* is present at the base of such developing roots as is often the case for *B. solanacearum*.

Adventitious root development induced in tomato by *Aplanobacter michiganense* was variable. In some cases the numbers were comparable to those induced by the bacterial organism causing wilt, but more often the numbers visible at the surface were few, and swelling and cankering of the stem occurred. Under humid conditions comparatively few of the root nodules grew out into the moist air and most of those that did so, rapidly browned and withered. Longitudinal and transverse sections through such roots showed the parasite invading and corroding the vascular system of the root. *A. michiganense* is primarily a phloem parasite and consequently is in a favourable position to attack root primordia shortly after they commence development Even at the nodule stage, considerable corrosion of the vascular tissues of the embryo root has been found to occur, this being responsible for their failure to develop further when placed under humid conditions.

Comparison of Bacterially Induced Roots and those induced by Growth Substance.

During the course of the above experiments comparative tests were made on selected plants using a synthetic growth substance (β-indole-acetic acid) applied in aqueous solution at an experimentally determined concentration (0.03 per cent. in water), which gave comparable stimulation responses to those observed in infected plants It was noted that adventitious root formation occurred in much greater abundance over a somewhat localized zone on the stem close to the point of uptake of the growth substance The systemic nature of bacterial invasion causing wilt makes this difference quite understandable. Where growth substance was introduced ir the vascular system of plants and travelled with the transpi ı, the syst invasion effect was paralleled in so far as leaf epinasty and adventitious root formation were concerned. Frequently stem bending was observed in tomato plants treated with growth substance, but no comparable effect has been seen in invaded plants. Swelling of the stem and increased cambial activity, after application of growth substance, has sometimes been paralleled in infected plants. Hunger (1901) recorded the development of adventitious roots on the petioles of plants infected by *B. solanacearum* and roots appear in this position on tomato plants treated with β-indole-acetic acid. Under normal glasshouse conditions the roots induced by the growth substance do not develop beyond the nodular stage, but under humid conditions they break through the epidermis and grow strongly out into the moist air for a distance of 1 to 2 inches. The time for this development, from the date of uptake of growth substance, varied between six and twelve days. When the plants were placed under humid conditions at the stage when nodules were

showing at the surface, two to three days sufficed for strong outgrowth. These times were similar to those for outgrowth of the roots in plants infected by *B. solanacearum*. When growth substance in aqueous solution was allowed to drain into stems of infected plants, which were already showing some degree of leaf epinasty and adventitious root formation, an additive effect was obtained in that more roots grew out and previously unaffected leaves developed epinasty. When growth substance in lanoline was smeared along the lower surface of a bacterially reflexed petiole the epinasty was overcome, and when the concentration was increased such previously reflexted petioles assumed a hyponastic position.

Histological Observations on Bacterially Induced Roots.

Considerable interest attached to determining whether the induction of adventitious roots by *B. solanacearum* was due to local action or to action at a distance Hutchinson (1913) and Smith (1914, 1920) were of the opinion that the development of adventitious roots occurred in the local absence of bacteria. Both show photomicrographs of developing roots and point out that no bacteria are present in the vessels behind them. From a detailed histological study of numerous infected plants the author believes that the picture presented by these workers must be modified. In transverse sections all conditions were found ranging from heavy bacterial blocking in vessels immediately behind the developing root to complete absence of bacteria. In the majority of cases, however, for tomato, sunflower, and African marigold stems, the bacteria were present in some vessels in the regions where adventitious roots were developing. Frequently the bacteria-filled vessels as viewed in transverse section were separated radially from the zone of root development by three to four locally non-invaded vessels, while in other instances bacteria were present in vessels on either side of the embryonic root, while the vessels immediately behind it were free. Typical conditions are represented in fig. 1 and Pl. XVI, fig 5.

Transverse sections, however, gave only a limited picture of the relation of the bacteria to the adventitious roots. A much clearer and more complete picture was given by combining observations on transverse sections with the examination of series of longitudinal sections, and observations on the path of vessel invasion as determined using a staining and maceration method (Grieve, 1936B), Using this latter method it was possible to demonstrate with a minimum of labour that the majority of the adventitious roots developed approximately along the lines of the larger primary bundles which were being invaded. In only rare instances did roots develop close to invaded median trace bundles

Where infected plants were large and a considerable amount of secondary growth had taken place, adventitious roots were found at points other than the large primary bundles. A study of longitudinal and transverse sections through stem regions bearing adventitious roots at various degrees of development (i.e., from root primordia in the incipient stage to well developed nodules visible at the surface) showed the following relations of the

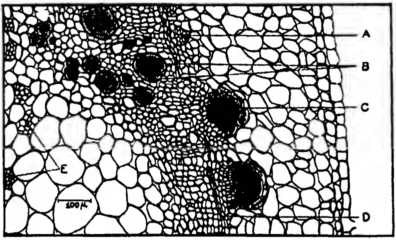


FIG. 1—Transverse section of tomato stem showing adventitious roots in relation to invaded vessels A = external phloem, B = vessels full of bacteria, C = Adventitious root, D = cambium, E = internal phloem Camera lucida drawing

bacteria to the roots:—(*a*) Adventitious roots frequently commenced to develop ahead of advancing columns of bacteria in vessels. (*b*) Bacteria were often found growing in the vessels closest to the stimulated root, but the presence of bacteria even in vessels which were separated by other tissues from the region of root development, does exert a stimulating effect (fig. 2). (*c*) Development of root primordia once initiated continues to the stage where the root becomes visible as a nodule at the surface of the stem, even though the bacteria during this period gradually block those vessels nearest the incipient root. Bacteria have even been observed passing into the tracheal system of a young root without immediately inhibiting its development (Pl. XVI., fig. 5). (*d*) Where most of the vessels in a main primary bundle were showing bacterial invasion, root primordia were stimulated to develop on either side of the blocked bundle (fig. 1). (*e*) Where the speed and completeness of invasion is very rapid so that

vessels are filled with the pathogen within a few days, leading to severe wilting, no adventitious roots have been observed to develop.

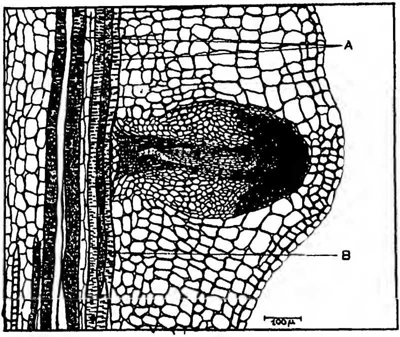


FIG. 2 - Longitudinal section through tomato stem showing relation to the bacteria to the young root A = vessels in which bacteria are present, B = vessel closest to root primordium No bacteria are present Camera lucida draw

Growth Substance and Adventitious Root Formation.

The production of adventitious roots, stem swelling and leaf epinasty in plants infected by *B. solanacearum* parallels these effects induced in healthy plants by the application of growth substances such as β-indole-acetic acid. This raises the question as to whether growth substance is associated with the formation of adventitious roots in such infected plants In an attempt to answer this, the growth substance content of equivalent stem portions of healthy and infected tomato plants, which were of closely similar size and equal vigour prior to inoculation, was compared. The agar diffusion method method of extraction of growth substance was used in preliminary experiments, but was discarded later in favour of the ether extraction method. Sixteen technically successful experiments were carried out but

only in five were there appreciable differences between the content of growth substance of healthy and infected plants. The results are set out in Table II.

TABLE II.—DIFFERENCE IN PLANT UNITS (AS PERCENTAGE OF CONTROL) BETWEEN THE CONTENT OF GROWTH SUBSTANCE OF HEALTHY AND INFECTED PLANTS

EXPERIMENT NUMBER	DIFFERENCE
3, 7, 18, 20, 22	+ 13, + 14, + 27, + 44, + 50
10, 12, 17, 19, 21	+ 1.5, + 1.4, + 2.4, + 3.5, + 1.4
4, 8, 13, 15, 14 .. .	− 3, − 1.9, − 3, − 2, 0

+ Indicates that infected plants contain more than the control The total content of the controls varied from 67 to 198 plant units

In spite of the large positive differences recorded in the first group of experiments, statistical examination shows that the difference between infected and healthy plants is not significant (either at the 1 or the 5 per cent. level) Further experiments of this kind are in progress, but it should be borne in mind that very small amounts of active substance suffice to cause marked stimulation effects and also that some of it would be used up in initiating the root primordia.

Should it eventually be found that there is a significantly greater amount of growth substance in infected plants showing root formation, it would still be necessary to discover its origin, that is, to find out whether it was produced as a result of bacterial metabolism or by the host cells as a reaction to invasion The approach to this problem must necessarily be indirect. In the case of Crown Gall some workers have shown that *B. tumefaciens* could produce growth substance in culture media Brown and Gardner (1936-37) and Link, Wilcox and Link (1937) inclined to the view that part at least of the stimulation effect was due to the production of heteroauxin by the pathogen It had been shown earlier (Grieve, 1939), that *B. solanacearum* produced a growth substance in culture media containing peptone, glucose and mineral salts. Further studies showed that both viru'ent and non-virulent cultures of *B. solanacearum* produced approximately equal amounts of growth substance as determined by the *Avena* test. The same result was obtained when pathogenic and non-pathogenic cultures of *Aplanobacter michiganense*, *B. tumefaciens*, and *B. flaccumfaciens* were tested. The active substance, extracted in crude form, gave positive tests for heteroauxin and induced adventitious roots on application to tomato and African marigold plants (Pl. XVI., fig. 3). The fact that all the organisms named above produce growth substance in culture

media irrespective of whether they are pathogenic or non-pathogenic, or of whether they produce stimulation effects in their host plants, makes it doubtful, that such a mechanism is necessarily involved in infected plants. Moreover, as Locke, Riker, and Duggar (1938) observed in the case of Crown Gall, the volume of culture which must be extracted and the number of bacteria present to give a small amount of growth substance, greatly exceeds the volume of sap and the number of bacteria present in the invaded plants, where the stimulatory effect is more marked.

On the question of the possible production of heteroauxin by the bacteria in the invaded vessels, more direct evidence was sought by an experiment which involved the uptake of the amino acid tryptophane into plants The rationale for this experiment was as follows:—The production of growth substance (hetero-auxin) by bacteria in media containing tryptophane follows the course of oxidative de-amination (Thimann, 1935)

$$\underset{\text{tryptophane}}{C_8H_6N.CH_2.CH(NH_2).COOH} + O_2 \xrightarrow{\text{bacterial action}} \underset{\text{hetero-auxin}}{C_{10}H_9O_2N} + NH_3 + CO_2$$

If such a process of oxidative de-amination was taking place in the invaded vessels where the amino acid tryptophane might be expected to be present, it seemed reasonable to assume that an artificial increase in the concentration of this substance would lead to a greater production of growth substance by the bacteria and the presence of this in turn would be reflected by more pronounced epinasty of leaves and adventitious root formation. To test this the following procedure was adopted. Ten tomato plants of closely similar size and of equal vigour were all inoculated with standard inoculum at the same height in a main bundle. Two days later 0.4 cc of a 0 5 per cent. concentration of l-tryptophane was allowed to drain from small tubes into the inoculated bundles of five of the test plants. At the same time 0.4 cc. of water was allowed to drain into the inoculated bundles of the other five plants Plants were examined from day to day for epinasty of leaves and adventitious root formation. No evidence was obtained, however, to indicate that any increased production of growth substance due to the addition of tryptophane occurred, the degree of epinasty and of adventitious root formation being approximately the same in both series. Wilting supervened earlier in the plants supplied with tryptophane and sections showed more bacteria in the vessels of these plants than in those of the control plants. Since 0.4 cc. of a 0.5 per cent. concentration of tryptophane when allowed to drain into a healthy plant has no deleterious effect, it is concluded that the tryptophane in the above experiment was utilized as a food source by the parasite and the increased numbers of bacteria caused the earlier wilting of the plants. This experiment lends no support to the hypothesis

that *B. solanacearum* produces growth substance by acting on naturally occurring tryptophane in the xylem sap It is possible that under certain conditions tryptophane present in the vessels may be acted upon to give heteroauxin, but the above result, taken in conjunction with the results for growth substance formation in culture media, makes it appear unlikely that the production of heteroauxin by the parasite plays any major role in the induction of adventitious roots in infected plants.

The alternative view is that the stimulation effects might be due to excessive production of growth substance by the plant tissues under the influence of the bacteria (suggested in the case of Crown Gall by Leonian (1937), and Locke, Riker and Duggar (1938)), or to its local accumulation in the tissues Data bearing on these possibilities have been obtained from experiments involving artificial blocking of vessels. Details of these will first be considered before passing to the hormone mechanism. It has been shown earlier in this paper that bacteria are present, generally in blocking numbers, in some stem vessels of tomato, below the points where adventitious roots commence to develop and it appeared desirable to test whether mechanical blocking could induce root formation.

The conditions of bacterial blocking were found difficult to duplicate as any attempt to block the xylem vessels involved interruption of at least the external phloem. This difficulty was partly obviated by combining experiments involving interruption of xylem and phloem by cutting, with others in which blocking substances were introduced into the xylem after cutting The cut stems served in the sense of controls to the cut and blocked stems. A positive result was obtained, as in several experiments roots developed for over 1 inch both above and below cut bundles blocked with such substances as cocoa butter, lanoline and paraffin wax-vaseline mixture, while in the control plants where only cutting was practised, adventitious roots were found to develop only in the immediate vicinity of the cut. In experiments reported earlier on mechanical blocking in relation to epinasty (Grieve, 1939) positive results were obtained in only three out of 40 experiments. It is of interest to note that further examples of epinasty induction by blocking were recorded in the present experiments, but the condition was not found to be constantly associated with the experimentally induced adventitious roots.

The results obtained in these blocking exeriments point to the possibility that where the invading bacteria are present in large numbers sufficient to block some of the vessels, the blocking effect may be an important factor in root formation. However, until a method of blocking the vessels with inactive substances without interfering with the phloem is developed, judgment must be reserved as to the closeness of the parallel and the importance of mechanical blocking.

The formation of adventitious roots above a cut on a stem has been explained on a plant hormone basis, as being due to the prevention of longitudinal transport of growth substance or root substance (Boysen-Jensen, 1936) and this explanation would appear to apply also in the case of the cut stems of tomato. In the cut and blocked bundles, the additive effect recorded may be explained either by envisaging a heightened production of growth substance in the vicinity of the affected parts or an accumulation of growth substance coming from other parts via either xylem or phloem. The first hypothesis appears to fit better the fact that adventitious roots form in the blocked region below a cut

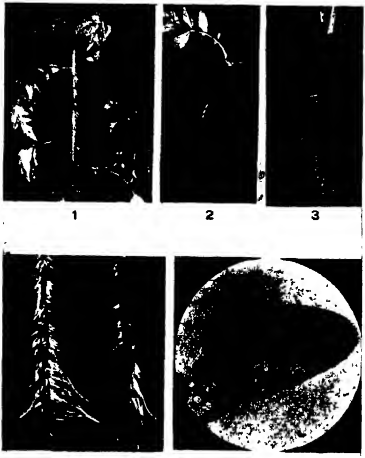
While as indicated above, caution must be exercised in making too close a parallel between the cutting and blocking of bundles of stems and the bacterial blocking of xylem, yet the results obtained, taken with the negative results for heteroauxin formation in the vessels, make it probable that the stimulation effects are due to an increase in local concentration of growth substance produced by the host cells which concentration is brought about by the presence of the parasite.

Disturbance of xylem-phloem relations by blocking of vessels and the accumulation in them of metabolic products (which are non-active physiologically) may both contribute to the increase in growth substance content leading to the formation of adventitious roots.

Summary.

1 A detailed account has been given of the development of adventitious roots in plants infected by *Bacterium solanacearum*. Comparisons have been made with similar effects induced by *Bacterium tumefaciens* and *Aplanobacter michiganense*, by synthetic growth substance (heteroauxin), by wounding and blocking of stems and by the influence of gravity. The relation of the invading bacteria to the developing roots was established by transverse and longitudinal sections, showing that the root primordia commenced development ahead of the advancing columns of bacteria in the vessels Development continued to the nodule stage even though the bacteria filled most of the vessels behind the root primordium.

2. Results of ether extractions gave no significant difference in the growth substance content of healthy and invaded stem parts. Nevertheless the close parallel between the formation of adventitious roots in infected plants and by synthetic growth substance, indicated that growth substance was associated with the adventitious root primordia. The question as to whether the active substance inducing the roots is produced by the pathogen or the host cells is discussed. The evidence so far available indicates that it is more likely that the stimulation effects are due to the increase or accumulation of plant hormone under the influence of the invading bacteria, rather than to a direct product of bacterial metabolism.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Explanation of Plate.

PLATE XVI.

FIG. 1—Infected tomato plant showing outgrowth of adventitious roots in humid air

FIG. 2.—Adventitious roots induced in *Tagetes erecta* on infection by *B solanacearum*

FIG. 3.—Production of adventitious roots in *Tagetes erecta* after uptake of growth substance extracted from media in which *B. solanacearum* had grown.

FIG. 4—Tomato stems infected by *B. solanacearum* showing outgrowth of roots when the cut bases are placed in water.

FIG. 5.—Transverse section of a developing adventitious root on an infected tomato stem. Note the presence of bacteria in the vessels leading to the vascular system of the new root.

[PROC. ROY. SOC VICTORIA, 53 (N.S.), PT. II, 1941.]

ART. XII.—*Studies of the Varieties of Subterranean Clover.*

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F R DRAKE, B Agr.Sc.

[Read 14th November, 1940, issued separately 26th July, 1941]

Introduction.

In Australia, the occurrence of varieties within the species of *Trifolium subterraneum* was first noted by Adams of Muresk College, Western Australia in 1924, and several varieties were described by him from 1924 to 1934 (1–7).

In Victoria, on the initiative of Mr. J. E. Harrison of the Department of Agriculture, a few samples obtained from each of the southern states of Australia were grown for observation in 1928. This preliminary work showed that a wide diversity of types existed and indicated the necessity for making a more extensive collection. This was arranged by Mr Harrison, and largely with the assistance of district dairy supervisors of the Victorian Department of Agriculture, a State-wide collection was assembled in the summer of 1928/29. Officers were requested to collect samples from fields in which the clover had appeared voluntarily, rather than from fields which had been sown with commercial seed This procedure, which was based on the knowledge that most commercial seed was of the one type, was adopted in order to overcome the possibility of assembling too cumbersome a collection, without reducing the collection of lots likely to show differences With the addition of further samples from Western Australia, South Australia, Tasmania and the United States of America, 143 lots were grown in 1929. To these were added collections from Europe and New Zealand in 1930 and 1931, while new samples from Australian sources have been collected since and grown each year.

In 1929, owing to the absence of Mr. Harrison, the first large collection was examined and classified by Mr. F. R. Drake of the Victorian Department of Agriculture, who continued his observations on selected units of this and other collections in the following years.

The most noteworthy feature of the first and subsequent collections was the remarkable uniformity shown by the plants grown from any one sample. In only eight lots of the first large collection was there any marked lack of uniformity and even these consisted of a mixture of only two or three distinct types. Approximately half of the same collection proved to be of the standard commercial type, generally described as a mid-season type or "Mt. Barker." The remaining lots, which included some very extreme types, differed from this standard type in one or more characters and provided sufficient material for a classification into early, mid-season, and late flowering strains (Plate XVIII) Differentiations were made within each of these groups according to minor variations in dates of flowering, and to such characters as habit of growth, location of first flower on the runners and colour or markings of stem, leaf, flower and seed. On this basis 39 strains were separated and noted in 1929, and though fresh collections have added to this number from time to time, the 1929 collection proved to be the largest and most fruitful source of variable material. The strains have been grown as separate plants in adjacent plots from year to year, and have exhibited an extreme stability of type. The practical aspect of the wide variations between strains has commanded most attention, and has led to the commercial development of a few very promising pasture strains.

In 1936, Miss Y. Aitken began a study of the subterranean clover collections, in order to formulate a scientific record of the strains which had been isolated, and to study their response to such environmental factors as length of day, temperature and saturation deficit.

The Type Variety of the Species in Australia, and its Variation, Phenotypical and Genotypical.

In Australia the most widely spread variety is that known as Mt. Barker. A description of an individual plant grown under standard conditions (fig. 1), and of its capacity for phenotypical and genotypical variations, gives a basis on which the known polymorphy of the species can be recorded and analysed; such a description is as follows.

A prostrate, villous, annual plant with a short main axis and strong lateral growth.

Seedling.—Epigeal, cotyledons glabrous, 5 mm. long, their stalks twice as long as their oval blades.

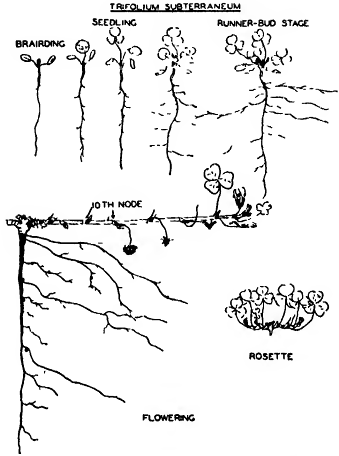

FIG 1—Stages in the development of a plant of *T subterraneum* —variety "Mt Barker".

Growth and flowering.—Each plant develops about five basal leaves, and then grows into its winter phase the rosette state, then from the basal nodes, about five prostrate runners are produced, each of these runners has about three nodes. In late winter with the onset of flower development (fig. 2*a*), the youngest internodes of the runners elongate slightly, while secondary laterals begin to develop from the basal nodes of the runners. By early September, the internode proximal to the first flowerhead elongates conspicuously, and by mid-September, the first flowerheads open. These develop at about the tenth node of each runner. Later, axillary flowerheads form at the more distal nodes and also occur on the secondary laterals. Towards the end of the flowering period,

after about nine flowerheads have formed along the runner, the later-formed internodes and peduncles are dwarfed, and few of the corresponding flowerheads form viable seed. After the formation of about sixteen runners, flowering at the top of the main axis prevents further runner initiation. According to Wexelson (25) the chromosome number in the vegetative stage is 16.

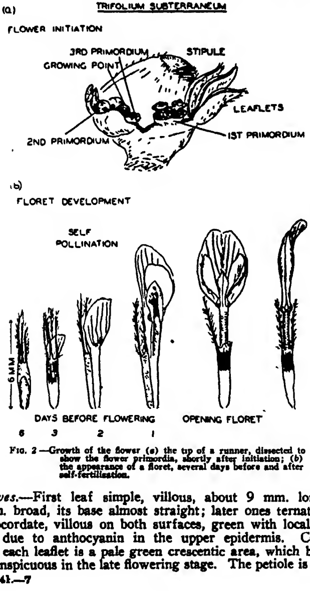

FIG. 2.—Growth of the flower (a) the tip of a runner, dissected to show the flower primordia, shortly after initiation; (b) the appearance of a floret, several days before and after self-fertilisation.

Leaves.—First leaf simple, villous, about 9 mm. long and 12 mm. broad, its base almost straight; later ones ternate, leaflets obcordate, villous on both surfaces, green with local brown flecks due to anthocyanin in the upper epidermis. Centrally across each leaflet is a pale green crescentic area, which becomes less conspicuous in the late flowering stage. The petiole is villous,

and four or more times longer than the leaf. The stipules are more or less villous, ovate-acute, attached in their lower halves to the petiole, typically red-striped over the veins and often red between the veins also.

Stems—The stems of the runners are villous, and green turning to brownish in spring, with exposure to sunlight as the internodes lengthen

Inflorescence.—Flowerheads axillary, each with three to five perfect florets, peduncle 1.5 cm long Floret about 12 mm. long; calyx tubular, yellowish below, red on half to two-thirds of the upper part of the tube with five green, narrow, free setaceous lobes a little longer than the tube, corolla white, with faint pink veins on standard and alae; standard three times as long as the calyx tube Self-fertilized, pollination occurring when the tip of the folded corolla is at the level of the tips of the calyx lobes (fig. 2*b*). The standard and alae expand fully two days later, and then the corolla withers, the pedicels become reflexed while the distal region of the peduncle becomes positively geotropic and bends down to the ground and lengthens up to 4–5 cm., thus forcing the developing fruits into the ground if soft. The peduncle tip forms a succession of four- or five-rayed to simple pronglike growths which are, morphologically, sterile and partly-developed flowers, these turn upward round the developing fruits and thus form the burr characteristic of the species. Each burr usually contains three to four seeds. Ovary with two anatropous ovules, only one developing to form a one-seeded fruit with a brown, membranous wall.

Mature seed—Purplish-black, dull-surfaced, oval except for the radicle notch, $1\frac{1}{2}$–$2\frac{1}{2}$ mm. long.

The characters entirely specific in the genus to *T. subterraneum* are (1) an inflorescence of very few perfect florets (2–5); after fertilization (2) the development of many spur-like sterile florets and (3) the occurrence of elongation and positive geotropism in the peduncle.

POLYMORPHY WITHIN THE VARIETY.

Phenotypical variation in such environmental factors as light intensity, temperature, competition and disease incidence may alter the appearance of the plant in several ways.

(*a*) Internodal length, the number of laterals along a runner, and the number of runners may be reduced by competition (see fig. 3*a*; Plate XVII., fig. 2) by insufficient water or nutrients or by disease. A small, sparse-leafed plant results. Extreme conditions reduce the rate of node formation.

Other things being equal, the date of germination influences the position at which the first flower is produced on the basal runners, and also the development of laterals (fig. 3*b*).

(*b*) The length of petiole and the size of leaves are also reduced by insufficient water-supply and by disease.

(*c*) The brown flecks and shading on the leaves and stem surfaces are prevented or reduced by shading from direct sunlight, or by mosaic infection. Attacks by the red spider cause a general red appearance of the leaves; while phosphate deficiency results in a purplish brown colour.

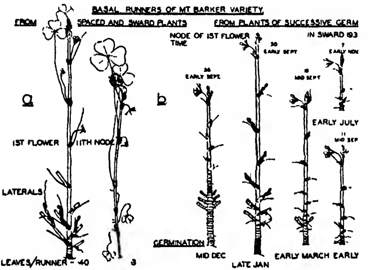

FIG. 3.—Basal runners of "Mt. Barker" variety, showing (A) the effect of sward, and spaced conditions, on lateral and leaf production, (B) the effect of date of germination in a sward, on lateral production, and on the node at which the first flower was produced.

Other abnormalities such as a marked dwarfing of the plant and a conspicuous reddening of the leaves have occasionally been noted, but not yet investigated.

Genotypical variations within the type variety are few owing to the close selfing of each plant. Probably the strains "White-Seed" and "Amber-Seed," may be regarded as variations due to a bud-mutation, preventing the development of the usual purple-black colour of the testà and of other anthocyanin markings in leaves, stem and flower. Such a bud-mutation certainly occurred on a plant of the variety Dwalganup when a burr with white seeds was found on a runner bearing burrs with normally coloured seeds. The following year the white seeds produced plants of the Dwalganup type but without anthocyanin in any part. "White-Seed" and "Amber-Seed" differ similarly from "Mt. Barker" and so also does a white seeded plant which

occurred in the 1940 plot of the variety "Bass." Variations from the normal recorded in the following section, may be due to similar mutations though no direct evidence has yet been found.

Polymorphy within the Species.

This survey of the hereditary variation within *T. subterraneum* shows a close similarity with that found in other closely-studied species of the Leguminosae. In Table 1, the variation of homologous characters of *T. subterraneum* is compared with those of *Pisum sativum* and *Vicia sativa,* after the plan of V. Muratova (17) and with the use of his data on *Vicia sativa* and with local data on *P. sativum.* Agriculturally it is particularly significant that forms occur with wide variations in respect to such important vegetative characters as length of vegetative period, lateral formation and size of leaf.

It should be noted also, that the record of variations within the other two species are the result of the study of an exhaustive world collection, whereas that for *T. subterraneum* is based mainly on Australasian types Hence the similarity in homologous variation may be expected to become even closer when more European forms have been collected and studied

At Burnley Gardens, Melbourne, observations of the various samples grown under the same conditions year after year, have shown that more than 50 varieties exist Each variety differs from the rest by at least one distinct character Table 2 lists the main characters of each variety.

Discussion of Major and Minor Characters.

Major Characters.

Major characters are those responsible for the detailed growth form and biological efficiency of the plant. These are:—

1. Number of runners per plant.
2. Lateral development (number of laterals per runner and degree of branching).
3. Internode length.
4. Leaf size and petiole length.
5. Number of seeds produced.

The number of runners per plant, the number of laterals and their degree of branching (figs. 4*a*, *b*) are strongly influenced by the inherited character of time of flowering, which may be considered to be an inter-related major character (Plate XVIII). The numerical production of stem growths (runners and laterals), which depends on these characters, largely determines the plant's capacity for the production of leaves and seed, as in the axil of each leaf a vegetative shoot or a flower may be produced. The four or five first produced, or "basal" runners

TABLE 1.—LIST OF THE HERITABLE CHARACTERS KNOWN TO OCCUR IN *T. subterraneum*, *Vicia sativa* and *Pisum sativum*.

—		T. sub	Vicia sativa.	Pisum sativum.
FRUIT—				
Size	small			+
	medium	+	+	+
	large	+	+	+
Number of Seeds	1	+		
	2	+		
	3–6		+	+
	7–12		+	+
SEED—				
Colour	white	+	+	+
	yellow		+	+ (12)
	green		+	+
	grey		+	+
	dull brown	+	+	+
	red brown		+	+
	brown		+	+
	black	+	+	+
Size	small			+
	medium	+	+	+
	large	+	+	+
FLOWER—				
Corolla Colour	white	+	+	+
	yellow		+	
	pink	+	+	+
	purple		+	+
	violet	+ (19)		
Calyx Colour	green	+	+	+
	with anthocyanin	+	+	+
INFLORESCENCE—				
Number of Flowers	1		+	+
	2–3	+	+	+
	4–7	+		
VEG. CHARACTERS—				
Formation of Laterals	feeble	+	+	+
	strong	+	+	+
" "	in axils of basal leaves	+	+	+
	scattered	+		+
STEM—				
Stem	long	+	+	+
	medium	+	+	+
	short	+	+	+
"	pubescent	+	+	
	glabrous	+	+	+
LEAFLET—				
Diameter	10–15 mm.	+		
	15–25 mm.	+	+	+
	25–30 mm.	+	+	+
	30–40 mm.		+	
Colour	anthocyanin	+		+
	none	+	+	+
Petiole	glabrous	+		+
	pubescent	+	+	
Petiole	anthocyanin	+		+
	none	+	+	+
Stipule	anthocyanin	+	+	+
	none	+	+	+
"	glabrous	+	+	+
	pubescent	+	+	
BIOLOGICAL CHARACTERS—				
Vegetative period	early	+	+	+
	late	+	+	+

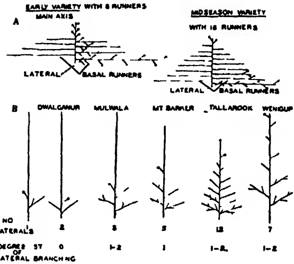

FIG 4 —Diagram to show (*a*) the relation between the number of runners produc per plant and the time of flowering (maturity) of a variety (main a' much lengthened) (*b*) types of runner structure resulting from variatic in number of laterals and degree of branching

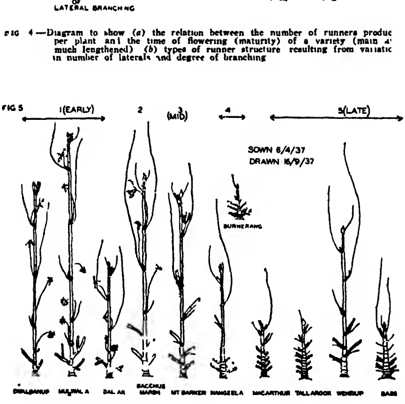

FIG 5 —Typical basal runners of varieties sown in early April, and drawn in mid September (laterals are not drawn in detail)

of a plant have been taken as typical, and observations and measurements confined to them. The combined effect of the major characters as above (except number of runners per plant) results in what may be termed a "basal runner organization" typical of each variety (fig. 5; Plate XVII., fig. 2).

1 Characters of the Basal Runner.

Time of flowering is a variable character influenced by time of germination, but if all the varieties are started together the relative time of flowering constitutes a reliable expression of the length of the vegetative period of each variety. As the rate of node formation per runner is approximately the same in all varieties during active growth, except towards the end of flowering, it follows that time of flowering determines the node on which the first flower is formed along the runner. This in turn determines the capacity of the variety for lateral formation, as lateral shoots only develop below the first flower of a runner. Time of flowering is also related to the time of commencement of internode elongation, and the length of internodes during flowering At Burnley, the date of commencement of flowering in the varieties ranges from early August to late October, but flowering dates coincide for many varieties, and for the sake of convenience the varieties may be separated into early, early mid-season, mid-season, late mid-season and late groups.

In Table 2, the varieties are listed from left to right in order of time of flowering. Reference to lines 26 and 15 shows that the number of the node on basal runners at which the first flower is formed, and the number of laterals per runner, increase with later flowering; while the internode length (line 14) following the fourth flower along the runner, tends to decrease. This character-complex is bound up with the photoperiodic response of the plant, which will be discussed later.

2. Development of Laterals.

This varies both in respect to their number and their degree of branching. Increasing lateness of flowering (as in (1) above) causes a range from 4th to 20th in the nodal number of the first flower, and from 1 to 16 in the number of laterals per runner. The first two or three, and sometimes more nodes, do not produce laterals, with the result that within the same time of flowering there is variation in number of laterals produced. The degree of branching of the laterals tends to increase with lateness of flowering (fig. 4*b*) and here again there is variation within the same maturity groups. Thus choice is possible of the most productive variety for a given length of growing season.

The variety Mulwala develops two or three double branching laterals per runner, but Dwalganup forms only one or two simple laterals. Tallarook with about ten laterals branching to the second or third degree differs markedly from Wenigup, with

only about five unbranched laterals. Burnerang has an extreme capacity for lateral formation and branching, even compared with the latest varieties.

3. The Commencement of Internode Elongation.

This occurs in the terminal internode at the same time as flower initiation at the growing point, but it is usually slight till the internode before the appearance of the first flowerhead, when the internode is from three to six times longer than the basal one. In consequence, though flower initiation in the varieties ranges from late May to early September, the conspicuous lengthening of runners does not begin till one or two weeks before flowering, except in two late varieties, "Rostock" and "Wenigup." In these, conspicuous elongation occurs more than a month before flowering. The length of the internode above the fourth inflorescence along the main stem of a basal runner is taken as a measure in line 14, of Table 2, because this was found to be the most satisfactory index of this character. The length of internodes at flowering, varies from about 5 cm. in the early varieties, to less than 2 cm. in the late ones. This results in the "stemmy" appearance of most of the early varieties compared with the increasingly compact later ones. In addition, the increase of laterals and hence leafiness, emphasizes the contrast. Three exceptions are "Daliak"—a compact early variety with short internodes, and short-stalked, small leaves, and Wenigup (Plate XVIII., fig. 12) and Rostock—"stemmy" late varieties with extremely long internodes and long-stalked, large leaves. The variety Burnerang is unique in its "bunched" appearance, which is due to a combination of extremely short internodes, both before and after elongation, and very profuse lateral-formation and branching. This results in the compressed laterals bending upwards and thus raising of the leaf level in the middle of the plant (Plate XVIII., fig. 15).

4. Leaf Size and Petiole Length.

The length of petiole and size of leaf tend to decrease with later-flowering varieties, but Wenigup and Rostock are exceptions in the late group, and Daliak in the early group.

5. Number of Seeds Produced.

The number of seeds formed per flower cluster, varies normally from three to four, but in "Reigert's White-seeded," normally only three flower primordia are initiated and develop into three-flowered clusters which ripen three large seeds. In Wenigup the flower primordia vary from two to four and two to three seeds are usually formed. In Burnerang, a high percentage of "twin" seeds are formed from the equal development of the two ovules in one or two ovaries of each cluster, resulting in four or five seeds per burr.

Minor Characters.

In addition to those variations in the above characters, which are regarded as having an important bearing on their agricultural significance, the varieties usually differ in minor characters such as anthocyanin development, leaf crescent, density and pubescence, etc. The varieties are still named after the district from which each was first collected, even though other varieties may occur in the same district. Exceptions have been made for several varieties which differ from one or other of the district varieties only in a minor character, which can be indicated in the name, e.g. Pink flowered, Red leaf (Plate XIX, fig 1), White seeded and Amber seeded.

The existence of a record of character combinations should obviate any confusion associated with locally named varieties It is interesting to note the amount of variation already found in some characters. Anthocyanin development in the leaf lamina may vary widely in amount, and its location may be any one of the types shown in fig. 6*b*. In the stipule (fig. 6*c*), it may be absent or may cause red striping over veins or diffuse red areas In the stem it causes a brownish green to dark brown appearance according to the number of epidermal cells affected; in the corolla, pink-veined white florets to dark pink ones; in the calyx (fig. 6*d*) a pink or brown tipped, or red-banded to red calyx tube; in the seed a black testa; in the germinating seedling (fig. 6*e*), a brown band on the hypocotyl. Its occurrence on the leaf may not be linked with its presence elsewhere, e.g. in the variety "Reigert's White-seeded" where it occurs conspicuously in all parts of the plant, except the seed testa. Conversely, absence of anthocyanin from all vegetative and floral parts is linked in several cases with a colourless testa, "White-seeded Dwalganup" and white and amber-seeded forms of "Mt. Barker."

The central pale green area, known as the "leaf crescent" in Mt. Barker, is absent from some varieties and in others varies from a central dot to a crescent stretching to the leaf edges (fig. 6*a*). It may be combined with the character causing white arms in the crescentic area (fig. 6, C4) in which case, the leaf crescent is very conspicuous (Plate XIX., fig. 2). The white area on the leaf surface is caused by the presence of air below the epidermis, which is separated locally from the palisade layer.

The combination of a leaf crescent with anthocyanin modifications, makes distinctive leaf markings for certain of the varieties, e.g., in Dwalganup, Second Northam, Reigert's White-seeded. Bacchus Marsh, Mt. Barker, Nangeela, Macarthur, Tallarook, etc.

The degree of hairyness is of special interest as so many of the early descriptions of the species describe it as "very hairy" (Table 3). Certain of the early flowering varieties are pubescent over all vegetative parts, and the length, density, and laxness of

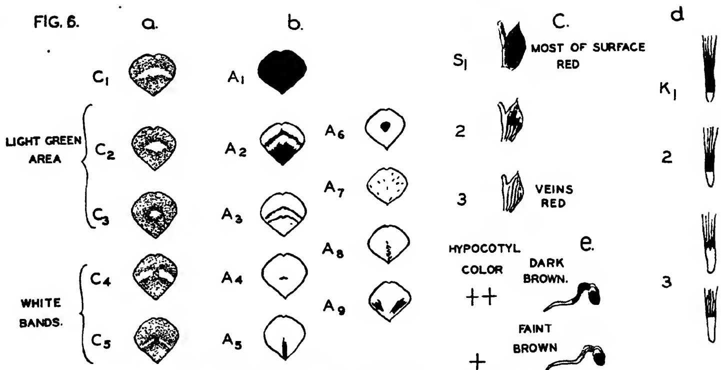

FIG. 6.—Inherited variations in the anthocyanin developed on leaf, stipule, calyx, and hypocotyl.

Table 2

E.

No.	Character	DWALGANUP	WHITE SEEDED DWAL.[P]	NUNGARIN	2nd NORTHAM	MULWALA	DALIAK	NORTHAM	SEIGERT'S WHITE	PINK FLOWERED	YARRA N.	SPRINGHURST	SEATON PARK
1	LEAF — COLOUR of LAMINA: Grass Green	+	+	+	+	+		+		+	+	+	
2	Mid-Dark Green						+		+				+
3	PATTERN of LAMINA: Pale Central Mark	C5 5	C5 6	C5 6	C1 8	C5 6	-	C1	C4	-	C1	C5 8	C5 W
4	Anthocyanin Upper Sur.	A2 7	-	A8	A8	A6	A7	A8	A8	A7	A2 7	A2 7	A6
5	Anthocyanin Lower Sur.	A8 7	-	-	A7	-	A7	A8	A8	A7	A7	A2 7	-
6	HAIRINESS: Upper Surface	++	++	-	++	++	+	+	P	+	++	+	P
7	Lower Surface	++	++	++	++	++	+	+	+	+	++	+	+
8	*SIZE: Diameter of Leaflet	S	S	S	S	S	M	S-M	L	M	S-M	M	M
9	PETIOLE: *Length	S	S	M	S	S	S	M	S	M	M	S	M
10	Colour	G	4	G	G	G	Gb	Bg	G	M	Gb	G	G
11	Hairiness	+	+	P	++	+	P	+	-	+	-	+	+
12	STIPULE: Colour	S3	-	S3	S3	S3	S1	S3	S1 8	-	S3	S3	S3
13	Pubescence	P	+	P	+	P	+	+	-	P	-	+	+
14	*INTERNODE: Length above 4th Flower	L	L	L	L	L	M	L	L	L	M	L	M
15	*LATERALS: Number per Runner	1-2	1-6	1	8	W	W	W	8	1-2	4	8	8
16	Degree of Branching	0-1	1-6	1	1-2	1	1	1	6	0-1	1	1	1
17	*RUNNER: Number per plant	S	S	S	S	S-M	M	M	S	S	M	S-M	M
18	STEM: Colour	G	M	G	G	Bg	W	Bg	G	Bg	Bg	M	G
19	Pubescence	++	++	++	++	++	P	+	-	+	-	+	+
20	Thickness			+	o								
21	FLOWER — COLOUR: Corolla Bud	P	$\boxed{W}$	P	W	P	W	P	W	S	P	P	S
22	Open Corolla	S	$\boxed{W}$	S	W	P	W	PW	S	S	W	W	W
23	Calyx Tube	S4	-	K2	K2	S4	K1	K3-4	K4	K4	-	K4	-
24	Calyx Lobes	W	G	G	W	G	W	M	W	G	W	G	W
25	Pubescence Calyx Tube	P	P	P	+	P	P	+	P	P	P	P	P
26	Node of 1st Flower	4-5	4-5	4-6	5-6	4-6	4-6	8	7	3-6	5-6	5-6	6-7
27	Time of 1st Flower	MID-AUGUST					LATE AUGUST						
28	SEED: Colour	Pp	W	Pp	Pp	Pp	Pp	Pp	M	Pp	G	Pp	Pp
29	SEEDLING: Hypocotyl Colour	++	-	++	++	++	+	++	++	++	-	++	

E.M.

No.	Character	BACCHUS MARSH	BURNLEY	MADRID	MILTON	HORSHAM	HILL'S SMALL	SAMARIA
1	LEAF — COLOUR of LAMINA: Grass Green							
2	Mid-Dark Green	+	+	+	+	+	+	+
3	PATTERN of LAMINA: Pale Central Mark	C1	C5 5	C3 W	C1	C1	C2	C1
4	Anthocyanin Upper Sur.	A7 W	A7	A2 7	A7	A7	A8	A8
5	Anthocyanin Lower Sur.	A7 W	-	A2 7	-	-	-	A7
6	HAIRINESS: Upper Surface	+	P	+	+	+	+	+
7	Lower Surface	+	+	+	+	+	+	+
8	*SIZE: Diameter of Leaflet	L	L	L	M	S	M	M-L
9	PETIOLE: *Length	L	L	L	M	M	L	M
10	Colour	Bg	Bg	Bg	Bg	M	Gb	Gb
11	Hairiness	+	P	P	+	+	+	+
12	STIPULE: Colour	-	S3	S3	-	-	S3	S8
13	Pubescence	+	+	+	+	P	+	+
14	*INTERNODE: Length above 4th Flower	L	L	L	L	M	M-L	M
15	*LATERALS: Number per Runner	3-4	4-6	3-6	5	4	6-7	4
16	Degree of Branching	1-2	1-2	1	1	1	1-2	1-2
17	*RUNNER: Number per plant	M	M	M	M	M	M	M
18	STEM: Colour	Bg	Gb	Gg	Bg	G	Gb	Bg
19	Pubescence	+	-	-	+	+	+	+
20	Thickness	M			M			
21	FLOWER — COLOUR: Corolla Bud	W	W	S	W	W	W	W
22	Open Corolla	W	W	W	W	W	W	W
23	Calyx Tube	-	-	-	-	-	S3	K3 8
24	Calyx Lobes	GG	W	M	W	GG	W	G
25	Pubescence Calyx Tube	P	P	P	P	P	P	P
26	Node of 1st Flower	7-8	8-9	8	6	6	6	5-8
27	Time of 1st Flower	EARLY SEPTEMBER						
28	SEED: Colour	Pp	Pp	Pp	Pp	Pp	Pp	Pp
29	SEEDLING: Hypocotyl Colour	+	+	+	+		+	+

M.

No.	Character	TEA	HOBENHOFF	MT. BARKER	WHITE SEEDED MT. B.	AMBER SEEDED MT. B.	RED LEAF	WENATON
1	LEAF — COLOUR of LAMINA: Grass Green							
2	Mid-Dark Green	+	+	+	+	+	-	+
3	PATTERN of LAMINA: Pale Central Mark	C1	C2- 1	C2	C2	C8	-	C8 4
4	Anthocyanin Upper Sur.	A7 6	A2 7	A6	-	-	A1	A6
5	Anthocyanin Lower Sur.	A6 7	A7	-	-	-	A1	A6
6	HAIRINESS: Upper Surface	P	+	+	+	+	-	+
7	Lower Surface	+	+	+	+	+	+	+
8	*SIZE: Diameter of Leaflet	M	M	M	M	M	M	M
9	PETIOLE: *Length	M	L	M	S	M	M	M
10	Colour	Gb	G	M	G	G	Bg	G
11	Hairiness	P	+	+	+	+	+	P
12	STIPULE: Colour	S8	S8	S8 W	-	-	S3	S3
13	Pubescence	+	+	+	+	+	+	+
14	*INTERNODE: Length above 4th Flower	M	M-L	M-L	M-L	M-L	M-L	L
15	*LATERALS: Number per Runner	8	6-7	W	3-5	3-6	W	4
16	Degree of Branching	1-2	1-2	1-2	1-2	1-2	1	1
17	*RUNNER: Number per plant	M	M	M	M	M	M	M-L
18	STEM: Colour	W	Gb	W	W	G	W	W
19	Pubescence	P	+	+	+	+	+	+
20	Thickness			M				
21	FLOWER — COLOUR: Corolla Bud	W	W	W	$\boxed{W}$	$\boxed{W}$	P	W
22	Open Corolla	W	W	W	$\boxed{W}$	$\boxed{W}$	PT	W
23	Calyx Tube	K3	K3	K3	-	-	K3	K3
24	Calyx Lobes	W	GG	G	W	G	W	G
25	Pubescence Calyx Tube	P	P	P	P	P	P	P
26	Node of 1st Flower	8-9	9-10	9-11	11	10	10	12
27	Time of 1st Flower	MID-SEPTEMBER						
28	SEED: Colour	Pp	Pp	Pp	W	G	Pp	Pp
29	SEEDLING: Hypocotyl Colour	+	+	+	-	-	+	+

L.M.

No.	Character	CASTERTON	HEXHAM	MANSFIELD	DERRINAL	BERALLA	BERLIN	MARONDELA	KYABRAM	BURRUMBANG	PANANTAPU	MERINO	MACARTHUR	RUAKURA SEL.[A]
1	LEAF — COLOUR of LAMINA: Grass Green													
2	Mid-Dark Green	+	+	+	+	+	+	+	+	+	+	+	+	+
3	PATTERN of LAMINA: Pale Central Mark	C8 5	C1	C2 1	C8 6	C1	C1 9	C5 4	C1	C8 3	C2 3	C8	C8	C5 8
4	Anthocyanin Upper Sur.	A8 7	A7	A2 6	A7	A2 7	A7	A7	A8 7	A7	A8 7	A7	A8	A7
5	Anthocyanin Lower Sur.	A8 7	A7	A6	A7	A7	A6	A8 7	A6	A2	A7	A7	-	-
6	HAIRINESS: Upper Surface	+	+	+	+	+	P	+	+	+	P	P	+	+
7	Lower Surface	+	+	+	+	+	+	+	+	+	+	+	+	+
8	*SIZE: Diameter of Leaflet	L	M	S	M	S	S	L	M	M	L	M	M	S
9	PETIOLE: *Length	M	M	M	M	M	M	M	M	S	M	M	S	S
10	Colour	M	G	Gb	G	G	G	W	W	W	G	G	W	-
11	Hairiness	+	+	+	P	+	+	+	+	+	+	+	+	P
12	STIPULE: Colour	S3	S8	S8	S8	S3	S3	S8	S8	S3	S3	S3	S3	S8
13	Pubescence	+	+	+	P	+	+	+	+	+	+	+	P	-
14	*INTERNODE: Length above 4th Flower	M	M	S-L	M	M	M	L	S	M	M	S	M	M
15	*LATERALS: Number per Runner	7	7	12	L	6	9	8-12	11	16	7	6-7	10	L
16	Degree of Branching	1-2	1-2	1-3	1-2	1-2	1-2	1-2	1-3	0-3	1-2	1-2	1-2	1-2
17	*RUNNER: Number per plant	W	M	M-L	L	M	M	M-L	M-L	W	L	L	L	M
18	STEM: Colour	W	Bg	Bg	Gb	W	Gb	M	G	M	Gb	Gb	Gb	G
19	Pubescence	+	+	P	+	+	+	+	+	+	P	+	+	+
20	Thickness											M-L	S	
21	FLOWER — COLOUR: Corolla Bud	W	W	M	W	W	M	W	W	M	W	W	S	S
22	Open Corolla	W	M	W	W	M	W	W	W	M	W	W	S	S
23	Calyx Tube	-	K3	S5	-	K3	S3 4	K3	K3	K3	K3	K3	K3	A3
24	Calyx Lobes	W	G	M	M	W	W	GG	W	G	G	W	G	G
25	Pubescence Calyx Tube	P	P	P	-	P	-	P	P	P	P	-	-	
26	Node of 1st Flower	11	11	14	13	11 12	11 12	13 14	15	13	12 15	14	13	15
27	Time of 1st Flower	LATE SEPTEMBER										EARLY		
28	SEED: Colour	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp
29	SEEDLING: Hypocotyl Colour	+	+	+	+	+	+	+	+	+	+	+	+	+

L.

No.	Character	TALLAROOK	BENICUP	ROSTOCK	FLINDERS	BODONGA	BLIER	PHILIP ISLAND	KYNETON	BASS	BASS WHITE SEEDED	RUAKURA FARM
1	LEAF — COLOUR of LAMINA: Grass Green											
2	Mid-Dark Green	+	+	+	+	+	+	+	+	+	+	+
3	PATTERN of LAMINA: Pale Central Mark	C8 9	-	C1	C1 9	C1	C1	C1 9	C1	C8	C8	C1
4	Anthocyanin Upper Sur.	A8 7	A7	A8	A8 7	A8 7	A8 7	A8 7	A2 7	A2 7	-	A8 7
5	Anthocyanin Lower Sur.	A2 7	A7	A7 6	A7	A6 7	A8 7	A7	A8 7	A8 7	-	-
6	HAIRINESS: Upper Surface	+	-	P	P	P	P	P	+	P	M	P
7	Lower Surface	+	+	+	+	+	+	+	+	+	+	+
8	*SIZE: Diameter of Leaflet	M	M-L	L	S-M	M	S	S-M	S-S	S	M	S
9	PETIOLE: *Length	S	S	P	S	S	S	S	S	B	S	S
10	Colour	G	G	G	G	Gb	Gb	Gb	G	Bg	G	M
11	Hairiness	P	P	-	+	P	+	+	+	+	+	P
12	STIPULE: Colour	-	-	S8	-	-	S3	S3	S8	S8 5	-	S8
13	Pubescence	P	P	-	P	P	+	P	P	P	P	P 8
14	*INTERNODE: Length above 4th Flower	S	L	L	S	S	S	S	S	S	S	M
15	*LATERALS: Number per Runner	12	8	L	10	12	11	10-15	14	8-12	8-9	11
16	Degree of Branching	1-2	1-2	1-2	1-2	1-2	1-2	1-3	1-2	1-2	1-2	1-2
17	*RUNNER: Number per plant	L	S	M-L	L	L	L	L	L	L	L	L
18	STEM: Colour	Gb	Gb	B	Gb	G	Bg	G	G	Bg	W	Gb
19	Pubescence	+	-	-	+	+	+	+	+	P	P	+
20	Thickness						Y-L	M	S	L		
21	FLOWER — COLOUR: Corolla Bud	S	S	W	S	W	W	S	S	W	$\boxed{W}$	W
22	Open Corolla	S	S	S	W	S	S	S	S	W	$\boxed{W}$	M
23	Calyx Tube	-	-	-	S3	-	K3	K2 3	A3	-	-	K3
24	Calyx Lobes	GG	G	G	GG	G	GG	G	GG	G	W	G
25	Pubescence Calyx Tube	-	-	-	-	-	-	-	-	-	-	P
26	Node of 1st Flower	15 17	15 16	13 17	13	16	16 17	17 18	13 16	17 16	17 16	13 16
27	Time of 1st Flower	MID-OCTOBER						LATE				
28	SEED: Colour	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	Pp	W	Pp
29	SEEDLING: Hypocotyl Colour	+	+	+	+	+	+	+	+	+	-	+

TABLE 2A.

LEAF.	STEM.	FLOWER.
Hairiness of Lamina—	*Length of Internode above 4th inflorescence of basal runner*—	*Corolla*—
— . No Hairs	S . ½ inch	$\boxed{W}$ .. White
F .. Few Hairs	M 1 inch	W .. White with pink veins
+ . Hairy	L 2 inches +	P . Pink
++ .. Very Hairy		P.T. Pink Throat
*		R Red
Fourth Leaf from Tip of Basal Runner—	*Number of Runners per Plant*—	
Size—Diameter of leaflet—	S . 5-11	
S .. 1 cm.	M 12-18	
M .. 1½ cm.	L . 19-25	
L .. 2½ cm.		
Length of Petiole—	*Stem Colour*—	SEED.
S .. 2 inches	B .. Brown	*Seed Colour*—
M . 3-5 inches	G . Green	W . White
L . 6 inches		B Brown
		Pp .. Purple-black
	Stem Pubescence as for Leaf—	
	* . Appressed hairs	
	Stem Thickness—	
	S . Slender	
	M . Medium	
	L . Stout	

TABLE 3.—VARIATIONS RECORDED FOR *T. subterraneum* IN EUROPE AND AUSTRALIA.

—	Hairiness. Plant.	Hairiness. Leaf.	Hairiness. Calyx.	Stipule Pink Striped.	Leaf Pale Mark.	Leaf Dark Flecks.	Corolla Coloured.	Calyx Red Bands.	Node First Flower.	Time of Flowering.	Number of Varieties.
ENGLAND.											
Curtis—London	+	+		+		+	−	+	2–3	June–Aug.	.
Smith	+	+	.	− +	.		.	.	.	.	.
Fitch and Smith	+		.	.	.			.	.		.
Hooker	++	+	.				−		1–2 ?	May–June	.
Trimen and Dyer—Middlesex	+								.		.
Bentham and Hooker	+							.	.		
Avebury	+						−		2–3 ?		.
Sowerby and Smith	+	++	.	+	− +(white)		−		4–7		.
Sowerby and Syme	−	++		−	− +		−		4–7		..
Pratt	+		..	−			−	+	4–6 *	May–June	.
Ray	..			.	.		−	.	.		..
Ross		+		+	.	.		..			.
Withering	+	+		.	.	.	−	.	.		
Hooker and Arnott	+	++	.				−		.		..
J. Hill, Flore—Britain, 1760	+	+				..			2–3 *		.
Davies, W.—J Min. Ag., 1927	+	+				− +	−	− +	.		.
FRANCE.											
Coste	+	.			.	.	−	.	.		..
Cosson and St. Pierre	++	++	+				−	.	.	May–July	.
Cosson and Germain Paris	.	++					−		.		.
Lamarck	+	.				..	−			..	.
Bonnier—N. France	+				.						
Grenier and Godron W.F Mid. F.	+				.	+ −	−				..
Spach—North France	+	.	.			..	−	.			..
Rouy and Foucard	+			.			−	−			.
GERMANY											
Huth	+	+		.	.		..	−	1–2	.	..
Reichenbach	− +		+	−		.	−	−	6–7 *	.	..
Hegi—Mid. Europe	+	.		..	.		−	.	..	..	..
SOUTHERN EUROPE.											
Boissier—Fl. Orient	+, ++			.			−				.
Linnaeus—France, Italy	+				.	.		.			.
Ascherson and Graebner	+, ++	+, ++	− +				+ −	+ −		.	4
De Halacsy—Greece	+	.	−						.	.	.
Willkomm and Lange—Spain	+, ++	.	.	−			−		.		..
Cocconi and Parma—Spain	+		+		.					.	..
Lazaro E. Ibiza—Spain						.	−			.	..
Fiori and Paoletti—Italy	+			.		.	−	− +			3
Bertoloni—Italy	+	.	.	−	+		−	−	..	..	..
Gay—Algeria	.	.	.	.	.		−	−	.	.	..
Post—Palestine	+	..	.	.	..	..	+ −	..	..	.	2
Ullmann	+, ++	+, ++	..	..	..	..	+ −	+ −	..	..	5

TABLE 3.—VARIATIONS RECORDED FOR *T. subterranean* IN EUROPE AND AUSTRALIA—*continued.*

—	Hairiness. Plant.	Leaf.	Calyx.	Stipule Pink Striped.	Leaf Pale Mark.	Leaf Dark Flecks.	Corolla Coloured.	Calyx Red Bands.	Node First Flower.	Time of Flowering.	Number of Varieties.
SOUTH AUSTRALIA.											
Black, 1909	+	..	..			.	–	+	..	..	..
" 1932	..	..	..	..	.	..	–	– +	..	Oct.–Dec.	..
WESTERN AUSTRALIA.											
Adams, A. B., 1927	++	+	..	.	– +	– +	–	– +	.	Aug.–Nov	4
" 1929	..	..	..	.		.	++		..	.	5
" 1930	..	..	.	..		++		.	..	..	6
" 1932	..		..		.	.	.	++	.	.	7
" 1934	..	.	.	..	..	.	.	.	..		9
" 1938	..	..		.		..	..		..	..	10
TASMANIA.											
Radel, 1936	++	+	.	–, +, ++	–, +, ++	–, +, ++	–	–, + ++	..	Sept.–Oct.	9 (from Vic., S.A. and W.A.)
SOUTH AUSTRALIA.											
Donald and Smith, 1937 ..	..	..	.	..	..	..		..	.	Aug.–Oct.	14 (from Vic., S.A. and W.A.)
NEW ZEALAND.											
Levy and Gorman, 1937 ..	..	..	..	– +	..	.	.	– +	..	Aug.–Oct.	15 (from Vic. S.A. W.A.)
VICTORIA.											
Harrison, 1936 .. .	+	..	.	–	+ (white)	..	–	–	15	Oct.	1 Late
Drake, 1940	++	..	..	–	+	+	–	–	8	Sept.	1 E. Mid.
Aitken and Drake, 1940 ..	–, +, ++	–, +, ++	– +	–, +, ++	–, +, ++	–, +, ++	–, +, ++	–, +, ++	4–20	Aug.–Oct.	50 V. Early—V. Late.

the hairs on the upper lamina result in a greyish green appearance of the leaf (Dwalganup, Springhurst, Pinkflower). Other varieties are less densely hairy with mid-green leaves (Mt. Barker, Bacchus Marsh), while others have glabrous upper leaf surfaces, having some hairs or being completely without hairs on petiole, stem and stipule (Reigert's White, Wenigup, Burnley) (cf. Plate XIX, figs. 3–6). The presence of hairs on the lower surface of the leaf lamina is the only degree of pubescence held in common by all the varieties.

Origin of Varieties.

The list of varieties in Table 2, includes all the available ones isolated so far in Australia, and Appendix I. lists the areas from which each type (except Mt Barker) has been obtained from 1929 onwards. So far the only indication of any particular area of concentration of varieties (cf. Vavilov (24)) is the preponderance of Victorian varieties in Table 2, but this is probably due to the more intensive search for them in this State. While there is no definite evidence to show that any or all of the varieties as they exist to-day were introduced accidentally from imported seeds or other material, there is also no evidence for an Australian origin of major variations.

Considering the varietal characters in two groups, (*a*) time of flowering (regarded as an expression of length of vegetative period, and capacity for branching), and (*b*) hairiness, anthocynanin, and leaf pattern, etc, only variations in respect to the first group are likely to be selected by the environment in a change of climate, such as from England to Southern Australia (Forster and Vasey (12)).

Combining with the Australian collection, the few varieties of direct European origin examined, one finds almost exactly the same range of maturity groups from both sources. Of the six European samples, those from Rouen and Berlin provided plants of both early and late maturity, while the others were pure lines in every respect; "Madrid" and "Liege" being early and similar to the early types from Rouen and Berlin, and "Cambrai" and "Rostock" being of the one late variety, distinct from the late Rouen and Berlin types.

No European variety exactly resembles any variety in the Australian collection, but the differences are only in "minor" and not in "major" characters, and if only the major characters are considered, counterparts can be found for each of the four European types in the Australian collection. The late variety "Rouen" is very close to "Kyneton" (Victoria); the early variety "Madrid" is much less hairy than the Victorian variety "Bacchus Marsh" of the same maturity group, and differs in

leaf markings; the variety "Rostock" is like the W.A. variety "Wenigup" in growth form and maturity, but differs in flower and leaf characters.

A survey of all available European descriptions and illustrations of the species (Table 3) shows few records of variations in minor characters and in node of first flower, and none of variations in leafiness. Only in 1934 did Ullmann (23) emphasize the practicability of selection of various maturity types, after a close study of Australian literature. He also described five European varieties (Appendix 2) varying in relative length of peduncle and petiole, in flower, calyx colour and in hairiness. The description of variety "longipes" fits our variety "Wenigup" and that of variety "brachycladum" is very similar to the variety "Second Northam." It is interesting to note in Table 3 that a form with a red banded calyx and striped stipules predominates in the English references, while a form with a green calyx and stipule is the one most described in French, German, Italian and Spanish records. Williams (27) found at Aberystwyth that the "Australian variety" (presumably Mt. Barker) had less anthocyanin flecking and colouring compared with the local native variety, but only a test under standard conditions, of samples from various English districts, could indicate the identity of the several red calyxed varieties with any in England, or with the variety "brachycladum" recorded in Italy (Appendix 2). Similarly, a much more extensive collection should be made in Europe and tested against the local varieties with green calyces, before their introduction here from abroad could be proved

Mutations may have occurred in Australia in such characters as anthocyanin distribution, though the only direct evidence so far is the discovery of the white-seeded "bud" mutation in Dwalganup quoted above.

Evidence as to the origin of maturity types is difficult to obtain. The commonly accepted explanation of the development of district or local ecotypes by the operation of environment on a population of mixed genetic constitution, can be applied to any of the normally cross-pollinated pasture plants, as any sample will show marked plant to plant variation. This process cannot apply with equal force to a self-fertilized plant like *T. subterraneum* in any variety of which there is a remarkable lack of variation from plant to plant, in characters which might allow of environmental selection or modification.

There is no evidence whatever of any heritable response to altered environment in any of the varieties grown at Burnley over a period, in some cases, of twelve years. Seed has been harvested from each variety and resown the next year, but the varieties have shown an extreme stability of type, with no alteration of flowering date or other major characters, under an environment often widely different from that of the district where collected. A survey of the natural occurrence of maturity

types in Victoria (fig. 7) shows some correlation of maturity type with length of growing season, as would be expected from Trumble's emphasis on the minimum length of growing season necessary for effective seed production, and regeneration of the early and midseason varieties (21). Examination of fig. 7 shows a preponderance of the early varieties in unirrigated areas with about seven months growing season, and of the late varieties in the districts of South Gippsland, with nine to twelve months growing season. The data used in this map for the length of growing season usual in Victoria, is part of that published in 1939 by Trumble (22). The occurrence of two areas in which the winter temperature becomes too low for growth, should be noted, and also the areas south of Swan Hill which have the warmest winter in the State.

Late varieties, even if introduced, are unable to seed and persist in short season districts, but an early variety is able to persist if introduced into a district which would support a later strain, especially if not subject to competition from a later strain. As is shown in fig. 7, many early and mid-season varieties have been obtained from areas which could support a later strain and in some cases do so as well as the earlier one. Thus the natural occurrence of a certain maturity type in any given locality depends on (*a*) the chance of its arrival, (*b*) the local growing season as controlled by climate and topography, being at least the minimum necessary for regeneration, and (*c*) its ability to compete with other varieties or species present.

A late variety, on account of its capacity for greater seed production, will tend to dominate an earlier strain in a district of long growing season, but several maturity types often occur either separately or in mixture in the same locality, e.g. at Smeaton, "Bacchus Marsh," "Smeaton" and "Mount Barker"; at Drouin, "Bass," "Mt. Barker" and "Dwalganup"; at Ballan, "Bacchus Marsh," "Mt. Barker" and a late type; at Tumbarumba, "Mt. Barker" and "Tallarook;" while around Benalla, early, mid-season, late mid-season and late varieties occur. In a district of short climatic growing season, such local environments as river flats or irrigated fields allow the predominance of much later types, e.g. "Tallarook" near Seymour and a late volunteer type at Rochester, and in low areas near Yea, Tylden and Ballarat, where the mid-season "Mt. Barker" or earlier varieties otherwise predominate.

The whole of the varietal distribution data suggest a chance distribution, with environment preventing the persistence of late types in short-season districts, and more effective regeneration (heavier setting of seed) favouring the dominance of late varieties in long-season districts. In intermediate districts, several maturity types may co-exist, although in competition there is usually a tendency for a particular type to dominate in any one position.

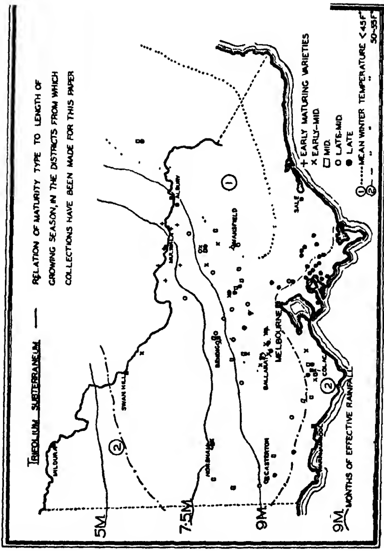

Fig. 7.—Map of Victoria, showing the relation of maturity type to the length of growing season, in districts from which collections have been made for this paper.

With no evidence of the occurrence of major variations in Australia, the evidence pointing to the accidental introduction into Australia of many of the varieties as they exist to-day, is summarized as follows:

1. The non-occurrence of any heritable alteration in major characters of the varieties when grown at Burnley over a period of twelve years, under changed environment.

2. The relatively short history of the species in Australia considered in relation to the extreme range of types isolated.

3. The absence of any closer correlation between the distribution of maturity types and the length of growing season of the district of their occurrence than can be explained as above (fig. 7 and discussion).

4. The existence in Europe of varieties differing only in minor, but not in major characters from certain Australian varieties.

This evidence appears to preclude the view that the varieties represent local ecotypes, developed in response to environment The important question of how and when maturity variations occur may be answered only by close study under controlled conditions of the present maturity types, in order to find whether heritable variations in maturity can be induced.

Relation of Time of Sowing to Growth and Reproduction.

As an essential to the elucidation of the biology of *T. subterraneum* and to its best use as a pasture plant, the influence of time of sowing on its growth and reproduction has been investigated.

Sowings were made at weekly or fortnightly intervals at the Agricultural School and at Burnley Gardens, between May 1936 and April 1940. Three varieties were selected for study, as being typical of three major groups of Subterranean Clover, differing in the flowering date when sown in Autumn. The early variety "Dwalganup," flowering in early spring, and the late variety, "Tallarook," flowering in late spring, were studied from September 1938 onwards. The mid-season variety, "Mt. Barker," flowering in mid-spring, was used from May 1936; all sowings were made from stocks of certified seed.

In addition, in 1938 and 1939, simultaneous sowings of stock seeds from nine varieties, were made at several centres in Victoria and Tasmania, and in 1940, at several centres in New South Wales. In 1938, 1939 and 1940, the photoperiodic response was studied on certain plots from May to September. Each sowing consisted of at least fifty plants, sometimes many more. They were sown at 3-inch intervals with about a foot between the rows. In all cases, the seeds were sown with superphosphate and the plants watered when necessary, so that germination was never inhibited by lack of moisture in any of those tests.

Observations were made on the dates of (*a*) brairding—the appearance of cotyledons above ground; the period from sowing to brairding, being the *brairding period;* (*b*) flower initiation—the appearance of the first flower primordium at the tip of a basal runner; this was found by dissection under a binocular microscope (fig. 2), the period from brairding to flower initiation being the *rosette period*; (*c*) first flowering—this was taken as the date when the first flowers had appeared on half the number of plants in the row of 50; the *flower development period* is from initiation to first flowering; (*d*) seed formation—i.e. when seeds have developed in the burr sufficiently to be capable of germination; the *period of ripening* covers the time from the opening of the first flower to its successful seed formation. "*The vegetative period*" is that from sowing to first flowering.

The accuracy of the observations on the stages of development was high during most of the year, and variations in spacing had no effect on the time of flowering. As in wheat (12), the flowering dates recorded for plants of the summer sowings were variable, being somewhat affected by disease—Rust (*Uromyces trifolii*), a type of mosaic, and Red spider (*Tetranychus*), but much more so by variations in the physiological response of the varieties at that season.

A. Effect of Time of Sowing on Development.

As will be shown in the succeeding sections of the paper, the time of sowing had relatively little effect on the time taken for the periods of brairding, and ripening, compared with its effect on flowering, which was primarily an effect on flower initiation. The influence of time of sowing varied greatly with the variety

Table 4—Showing data for time required for germination of soft seeds of three varieties of *T. subterraneum*

Incubator.		Field.		
Temperature °C	Days to Production of Free, Green Cotyledons.		Soil Temperature at three inches Depth—Range of Fortnightly Means	Time of Year.
		*		
30	2·9	..	.	..
25	3·1	6	20-28	Nov.-Feb.
20	4	..	.	.
15	6	10	17–19	April
10	9	17	10	July
5	22	.	..	..

* In the Field Tests, the seed was planted at about 3/8ths of an inch.

(1) *Brairding*.—In all varieties, the brairding period varied from six days (November to February) to ten days (early April), and to seventeen days (early July). It seems clear that this range could be reasonably attributed to soil temperature alone, as previous laboratory experiments had shown that in no variety did light affect the rate of germination of the seed. Table (4) compares the time taken, under various temperatures, for germination of the seed to the stage of free, green cotyledons, under laboratory and field conditions. The variation in the time taken for brairding in the field is of the same order as that taken under equivalent laboratory temperatures, but is relatively slower. This difference is more apparent than real, and is due to the impractibility of obtaining exactly comparable stages and conditions in the field and in a laboratory.

(2) *Flowering*.—During 1937 and 1938, observations were made on dates of seeding, brairding and flowering, and in 1939 and 1940 on the date of flower initiation also. Data for 1938 and 1939 have been arranged in fig. 8 to show the relation between time of sowing, and flowering, in the three varieties. Less than the number of observations are shown in these and other graphs for the sake of clarity, but no aberrant cases have been omitted

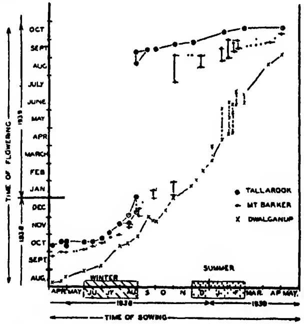

Fig 8.—Graph showing the effect of time of sowing on time of flowering in three varieties in 1938 and 1939

In the "Tallarook" variety, the plants sown at the usual time in early autumn (April), flowered in early October, after a vegetative period of six months. Sowing up to July reduced the vegetative period, but the date of flowering remained the same. Plants of the mid-August sowing, showed some variation in time and node of flowering (shown in the graph as a vertical line between the dates of first and last plants to flower). Some individuals were as much as four weeks later than others, instead of the normal difference of about one week. The late August sowings gave a few plants with runners which began flowering in December, but then died back, though the rest of the plant, and other plants of the row remained vegetative till the end of August 1939 From mid-August to late August is termed the "critical period" of sowing, because of the resultant variable flowering dates. The sowings from September onwards, produced plants that began flowering from the next September. Thus, there was a period of eight months vegetative growth between the flowering of the August sowings and that of the September ones. This behaviour recalls that of winter wheats sown in summer. (See fig. 2, Forster and Vasey (12).)

The results for "Mt. Barker," are comparable with those for "Tallarook," but certain differences are obvious from fig 8. Attention is drawn to the fact that the critical period ends two months later, and, on the whole, the vegetative period is shorter for "Mt Barker," whatever the time of sowing.

The behaviour of the "Dwalganup" variety showed marked differences from the other two. Plants sown in early April, flowered in August, a month before "Mt. Barker," and the date of flowering became progressively later with successive sowings. The critical period was from mid-January to the end of February, there was no period of complete cessation of flowering During this period occasional plants entirely failed to flower and those which did develop, were confined to one or two runners. Sometimes there was a difference of two to three months between the flowering of runners on the same plant. The runners that flowered, varied in position from basal to younger ones, but once a runner started to flower, it proceeded normally.

It is noteworthy that the sowing of mid and late varieties during Summer, results in the plants flowering at about the same time as those sown in Autumn. This has also been noted from observations on self sown swards at Burnley, and at the Werribee Research Farm, where plants of mid and late season varieties, which had germinated in January, flowered in the same week as those sown in April (see also 6, 8, 10, 16).

In fig. 9, the vegetative periods for the three varieties are plotted against their respective times of sowing for 1937-40. It will be seen that the time of sowing has a great effect on the

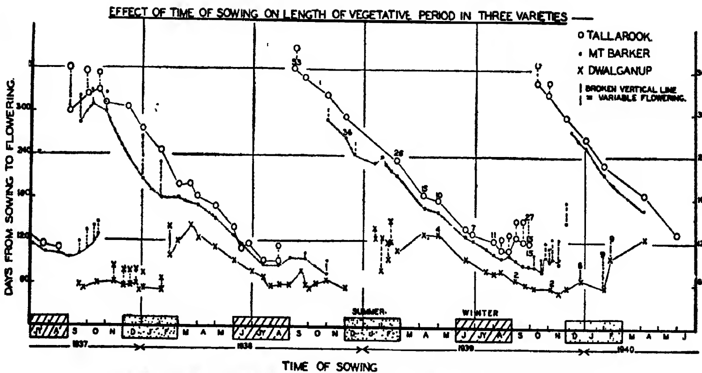

FIG 9.—Graph showing the length of vegetative period in relation to time of sowing in three varieties, 1937 to 1940

length of the vegetative period, which diminishes as sowings progress from Summer to the next Spring. The magnitude of this effect is summarized in Table 5.

TABLE 5.—EFFECT OF TIME OF SOWING ON LENGTH OF VEGETATIVE PERIOD, IN THREE VARIETIES OF EARLY, MID, AND LATE MATURITY. (Sowing from September, 1938, to August, 1939.)

Variety	Longest Vegetative Period.		Normal Vegetative Period.		Shortest Vegetative Period.	
	Months.	Time of Sowing.	Months.	Time of Sowing.	Months.	Time of Sowing.
"Dwalganup" (early)	4	April–May	4	Early April	1¾	September to January
"Mt. Barker" (mid.)	9	Late November	5	Early April	2½	Early October
"Tallarook" (late)	12	Early September	6	Early April	3½	August

The problem is seen to be more complex, when the position of the flower on the basal runners of the plant, is examined. In fig. 9, for the 1939 observations, the node at which the first flower was produced, is indicated at several locations on the graphs. Immediately after the critical period in each variety, when the period of vegetative growth is at its longest, the number of the node at which the first flower is produced is highest. For the three varieties, the numbers of the nodes at which the first flowers form, from these sowings, are 50, 36 and 4 respectively. In plants originating from sowings immediately before the critical period, the corresponding figs were 7, 6 and 2 respectively. Plants originating from the critical period of sowing, show an increasing variation between individual runners.

The season has some influence on the onset of the critical period, as is shown by a comparison of the years 1937 and 1938, with 1939. This will be discussed later.

(3) *Flower Initiation.*—It was of some interest to discover whether the variability in flowering was due to an effect on flower primordia formation, or on flower development. This was investigated for the three varieties in 1939 and 1940. The results for "Mt. Barker" are set out in fig. 10, which shows that the primary influence is on primordia formation. Fig. 11 shows, for all three varieties, the length of the interval between primordia formation and flowering, and also in many cases, the number of the node at which the first flower appeared. It seems reasonable to assume that the changes in the length of the flower development period from month to month, are explicable as an effect of temperature on the rate of growth of the primordia.

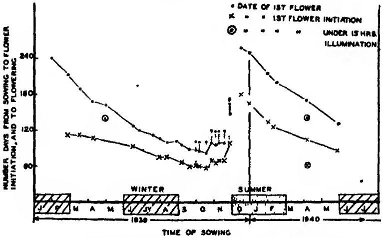

FIG 10.—Graph showing the length of time from sowing to flower initiation, and to flowering, and hence the relation between flower initiation and flowering in "Mt Barker" variety

Such a temperature effect was observed in the rate of node formation along a runner; the rate increased from mid-winter to the summer months, being fourteen days per node in winter, and only four days in the summer.

Fig. 11 also indicates the time at which flower initiation begins. For "Tallarook," the earliest flower initiation began in mid-August, and continued normally till the beginning of November;

DIAGRAM—ILLUSTRATING RELATIONSHIP BETWEEN INCIDENCE OF FLOWER INITIATION AND TIME OF FLOWERING

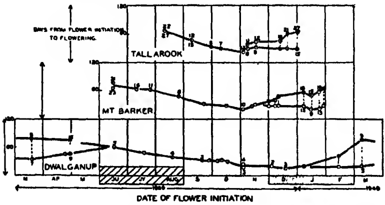

FIG 11.—Graph showing the relation of the length of the period from flower initiation to flowering, to the date of flower initiation, and the incidence during the year of the beginning, variability and end of initiation for the three varieties

for "Mt. Barker" the corresponding period was from mid-June to the beginning of January; and for "Dwalganup," flower initiation occurred all through the year, but was somewhat unstable between February and March in 1940, and March and April in 1939.

(4) *Seed-formation.*—The time taken for seed-formation, varied from one month after flowering in October, to about three months, after flowering in May. Exposure to a fifteen hour length of day in the winter did not hasten the period, and it is apparently dependent on the temperature only The developing embryo may be killed a few days after flowering, through desiccation in summer, or by low temperatures in winter

A wide variation in size of seeds often occurs along a runner, due to the time interval between the flowering of the first and the last axillary inflorescences along a runner, and to the decreasingly favorable conditions for seed development during this period

Comparing the April sown varieties at Burnley, the minimum time taken for seed formation varies from about six weeks for the early varieties, to five weeks for the mid-season ones and to four weeks for the late ones. For the main maturity types, the total period necessary from sowing to seed formation, for minimum regeneration is thus assessable, and can be compared with the average length of growing season of any district

B Discussion

It is obvious from the preceding sections, that the time of sowing has a marked effect upon the length of the vegetative period, and on the time of flower initiation and flowering (The less marked effects on brairding and flowering will not be discussed here.) There is ample evidence in other work, that these effects might be due to the differences in length of day, to which the plants from the various sowings were subjected during their development An experiment on Subterranean clover itself, has shown that a continuous, long period of daily illumination may cause earlier flowering. Certain plants were treated from May to September, with an extra period of artificial illumination the intensity of which was 30-foot candles at plant level The total period of continuous illumination was fifteen hours in each twenty-four This treatment, applied to plants of each variety, sown in April and in February, caused the flowers to appear three or more weeks earlier than on the controls. As might be expected, the plants whose vegetative period had been reduced by the "long day," produced flowers on nodes nearer the axis, i.e., these plants resembled morphologically, field plants produced by sowings just before the critical period. Thus while the node number of the first flower in "Dwalganup," was reduced

from four to two, in those of "Mt. Barker" it was reduced from ten to six, and in those of "Tallarook," from fifteen to seven (Plate XVII., fig. 1, and cf. fig. 9). It is concluded that the later the variety, the greater the response to a summer length of day, in respect to the "node number."

Examination of fig. 12 will show however, that the interpretation of the field data is by no means as simple as is suggested by these experiments on the effect of increased daily illumination. The variations in the length of day experienced throughout the year in Melbourne, are plotted as a heavy line on the upper section of fig. 12; the mean minimum weekly temperatures from September, 1938, to December, 1940, are shown as a fine line. In the lower section, length of vegetative period, flower initiation, and flowering during this period, are arranged horizontally, in the order of sowing. The data is for "Tallarook."

There is some indication that the length of day may affect the date of flower initiation in the field. Thus at *E*, the time from sowing to initiation is five months, and the length of day ranges from 9½ to 11 hours. As the length of day increases, the time from sowing to initiation decreases, partly due to an increased rate of growth, but also, to initiation at a lower "node-number"; e.g. at *A*, where the node-number is only seven, compared with that of fifteen resulting from the sowing at *E*.

Comparing the group of sowings from *A* to *B* however, it can be seen that they all have about the same vegetative period. But the plants sown at *A*, had an average length of day of 10½ hours, and flower initiation began before it reached 12½ hours per day, whereas those sown at *B* germinated when the length of day was 12½ hours, and began flower initiation when it reached 15 hours per day. Intermediate sowings gave intermediate results. Here, obviously, the average length of day during the growing period is not correlated with the time of initiation or the length of vegetative period. Comparing those plants sown at *C*, and at *D*, it is clear that they are both subjected to approximately the same length of day (rising from 11 to 14½ hours per day), during the first two months of their vegetative life. Those at *C* formed flower primordia in early November 1938 (two months after sowing), but those at *D* failed to form primordia till August 1939 although experiencing a length of day of 14 to nearly 15 hours from November to February. Thus it is clear that some factor or factors, in addition to day length, must affect flower formation, at any rate during Spring.

The incidence of high temperatures was then analysed, as it had been shown experimentally by Hamner and Bonner (14), and Roberts and Struckmeyer (20), that night temperatures above a certain level prevented flowering in a number of plants, including some legumes, despite a favorable length of day. The

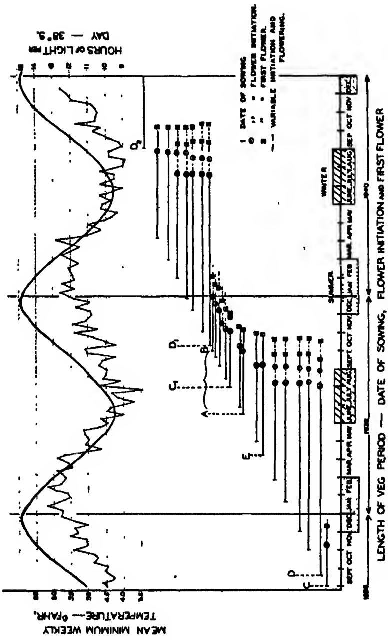

FIG. 12.—Graph, showing the relation between length of day and mean minimum temperature, and the behaviour of plants sown in the years 1938 to 1940

figures for the mean minimum weekly air temperatures are therefore given also in fig. 12. It is evident that the temperature rises and falls with the length of day, but the maxima and minima occur about a month later in each case.

Referring again to the sowings at *C* and *D*; the plants sown at *C* developed under a night temperature increasing from 45°F. to 50°F. But the temperature only rose above 50°F. the week before flower initiation, and it fell to 50°F. again, for the next two weeks, before rising above this level continuously for the next four months Those sown at *D*, however, experienced a rise in temperature to above 50°F several weeks before flower initiation would have occurred, judging from the time taken in plants of the previous sowing The remarkable difference in the flowering dates for *C* and *D* is shown in fig. 12.

Considering the behaviour of plants sown in the spring of 1939, at D_1 temperatures above 50°F. became continuous two months after sowing, and again flower initiation did not occur till the next July

Plants sown from C_1 to B, correspond to those of the previous year, sown at *C* That is, they are not subjected to continuous periods above 50°F., and they have a short vegetative period. These plants showed an increasing variability of flower initiation, and it can be seen that flower initiation in this group occurs over the perod when the temperatures were fluctuating about 50°F

Considering the results in both years, the first sowing resulting in a prolonged vegetative period, occurred earlier in the spring of 1938, than in that of 1939, it is clear that the temperature level rose continuously above 50°F., earlier in 1938

It is therefore concluded provisionally, that the failure to flower, in plants sown just after the critical period, is possibly due to the incidence of high temperatures. If the weekly minimum temperature rarely falls below 50°F at a time when flower primordia could normally be formed, then it seems that even under the most favorable length of day, flower initiation is inhibited If this explanation is correct, then it follows (see fig. 12) that this temperature effect is not rapidly reversible, for even when the temperature has fallen well below 50°F., the plants sown at D_1 still remain vegetative for four months They finally form primordia, when the temperature is between 40° and 45°F., and the length of day only 10½ hours.

There is, however, another possible explanation of the prolonged vegetative period in the plants of type *D*. It may be that flowering is delayed not because of a high temperature but because of the lack of a suitably low temperature. In the normal vernalization theory, as applied to wheats, the low temperature "thermo-stage" must precede the "photostage." Applying this to clover we note that plants sown between *A* and *B* pass the

early stages of their vegetative life when the temperature is between 35° and 45°F. and they flower after a relatively brief vegetative period. Plants sown at D_1, however, experience a high temperature (as well as a long day) during their early vegetative life and do not form primordia until late winter, when the temperature has again fallen to between 40° and 45°F. The evidence therefore allows the suggestion that the plant must receive at some time in its vegetative period, and not necessarily before it receives the long day, a period of low temperature before flower initiation can take place

If the view is adopted that flowering is inhibited by high temperatures, then the data indicate that the inhibition temperature is near 50°F. for "Tallarook," 53°F. for "Mt. Barker" and about 58°F. for "Dwalganup" A temperature level sufficient to prevent flower initiation in "Dwalganup" is not reached in Melbourne, but the critical period of flowering in this variety is associated with fluctuations about the 58°F. level. If we adopt however the vernalization hypothesis (i e necessity for a low thermo-stage) then it may be that "Dwalganup" differs from the other two varieties in not requiring temperatures below 45°C. during its thermo stage Only further experiments can distinguish between the two hypotheses, and these are now being undertaken.

C. Effect of Latitude and Season on Time of Flowering in Autumn Sown Plants

It has been shown that with autumn sown plants, the later the variety the greater the response to a long daily period of illumination; and that the earliest flower initiation possible in "Tallarook" varied between the end of July to the middle of August, with a length of day increasing from 10 to 11 hours. Conversely, the earliest variety could initiate flower primordia all through the year, though it could be hastened slightly by lengthened daily illumination. It might thus be reasoned that the late variety grown in more northerly districts in southern Australia, would show earlier flowering due to the earlier incidence of a length of day of more than 10 hours, and conversely with districts south of Melbourne. To investigate this effect of latitude, sowings of nine varieties of early to late maturity were made at places ranging from Launceston to Sydney.

Typical results of such sowings are shown in Table 6, but only those for the varieties "Dwalganup," "Mt. Barker" and "Tallarook" are included as they are representative of the early, mid and late maturity groups.

Considering the varieties sown in early April of 1938, those at Walpeup flowered about a week earlier than those at Burnley, but of those at Launceston, the late variety flowered at the same

TABLE 6.—EFFECT OF DISTRICT OF SOWING ON THE TIME OF FLOWERING OF VARIETIES, WHEN SOWN AT THE SAME TIME.

Places Where Tested.	Latitude.	1938.			1939.			1940			Incidence 11-hour Day in Spring.	10-hour Day.
		Dwalganup	Mt. Barker	Tallarook.	Dwalganup.	Mt. Barker	Tallarook.	Dwalganup.	Mt. Barker	Tallarook.		
Sown April 8.												
Sydney	33°·5	.	.	..	..			July 25	Sept. 4	Sept. 25	Aug. 19	July 6
Canberra . .	35° 2	.	.	..	.	.		Aug. 28	Oct. 5	Oct. 23	„ 20	„ 12
Walpeup . . .	35°·1	Aug. 10	Sept. 19	Oct. 4	Aug. 12	Sept. 25	Oct 5	„ 17	Sept. 21	„ 7	..	..
Rutherglen	36°	„ 12	„ 25	„ 6	„ 12	„ 27	„ 9	.	..	..	..	..
Burnley	38°	„ 15	„ 27	„ 12	„ 17	„ 27	„ 24	„ 14	„ 22	„ 5	„ 24	„ 7
Launceston	41°·2	Sept 5	Oct. 3	„ 11	Sept. 7	Oct. 10	„ 24		.	.	„ 28	Aug. 1
Sown April 28.												
Swan Hill .. .	35°·2	Aug. 20	Sept. 21	Sept. 25	.	..	Sown April 29 Kerang (35° 4)	Aug. 25	Sept. 25	Oct. 12	..	..
Cohuna	35°·4	„ 16	„ 21	Oct. 3	..	..	..	..	..	..	..	..
Burnley	38°	Sept. 1	Oct. 1	„ 13	..	..	.	..	..	..	..	..
Launceston	41°·2	„ 23	„ 7	„ 14	.	..	..	..	..	..	..	..

time as that at Burnley; the mid-season one was a week later, and the early one was three weeks later. At Walpeup in 1939, only "Tallarook" flowered much earlier than at Burnley, while at Launceston the late variety again flowered at the same time as at Burnley. Taking a length of day of 11 hours as probably necessary for flower initiation in "Tallarook" plants sown in autumn, it can be seen in Table 6 that this is reached by Aug. 24, at Melbourne, and only four days earlier and later respectively, at Walpeup and Launceston The difference is comparatively small, and also, no clear gradient is obvious in the commencement of flowering of the late variety in the three places. The difference between the results of the earlier varieties at Melbourne and Launceston is much greater than between Melbourne and Walpeup, and the later flowering of "Tallarook" in 1939, compared with 1938 at both Burnley and Launceston, is also noteworthy, as occurring when a cooler spring period was experienced over these districts. In addition, the node at which the first flower was produced along the basal runners, did not vary in number, as would have occurred with a sufficiently wide difference in incidence of the favorable length of day. It may be reasonably concluded that differences in temperature levels experienced in the various districts, affect the rate of vegetative growth of the varieties, and so their times of flowering. This is further supported by the observation that the plants reached certain stages in their growth (such as that of four leaves per plant) earlier, when growing in the northern districts, and later, when growing at Launceston; and that flower initiation in "Tallarook" was some days earlier at Walpeup and Kerang, than with plants sown at the same time in Melbourne.

In 1940, results were also obtained from Sydney and Canberra. Comparing them with those from Walpeup and Burnley, it is interesting to note that the first three places have approximately the same incidence of an 11-hour day, but the flowering of all three varieties is much earlier at Sydney, and much later at Canberra than at Walpeup. Reference to such a measure of temperature levels as the average monthly minimum temperature, shows that the figures for Sydney, from June to September are from 7° to 4°F. above those for Melbourne, while for Canberra, they are from 9° to 7°F. less than those for Melbourne.

Within the range in length of daily illumination occurring from Launceston to Sydney, the effect of decreased latitude for the plant appears to be due to the associated trend in climate from cool to warmer, and where two districts of the same latitude differ sufficiently in the temperature levels of the growing season, the varieties will show the differences, in their commencement of flowering.

Observations on Production According to Variety and Environment.

Most of the following notes on the comparative productive capacity of varieties have been taken on the spaced plants in the plots at Burnley Gardens. Growth under such conditions gives any plant the chance to show its full productive capacity, and also allows comparative study of varietal development; whereas under sward conditions, lateral development, functioning leaves, number of runners, and hence differences between varieties, are much reduced. These observations are thus preliminary to the essential investigation of varietal production in relation to sward conditions and to length of growing season. They are, however, free from the effects of the factors of competition, which may act differentially between varieties

From two to four typically developed plants were used for each measurement The quantitative data obtained from these observations were scarcely likely to be statistically acceptable, as the basis of detailed hypotheses, but they were sufficient to give information on varietal differences of a major type.

Time of varietal differentiation in leaf, dryweight, and burr production.

To ensure that the varieties could be compared in their development, observations were taken on those plots in which they had all germinated in the second week in April

It has been pointed out previously, that many of the varieties differ greatly from each other in leaf and dryweight production at flowering time, owing to variations in runner development. A periodic count of leaves per plant in 1940, the results of which are set out in Table 7, showed that this variation commenced in late June, after which date, initiation of new runners was slower in the early variety, "Dwalganup," and the late one,

Table 7.—Comparative leaf development in varieties at various dates—1940

Maturity	Variety	Number of Leaves per Plant at—					
		July 1	Aug 1	Aug 22	Sept 17	Oct 15	Nov. 15
V.E. ..	Dwalganup	15–20	20–30	15–25	40	120	120
V.E. ..	Mulwala . .	20	30–40	25–30	100	200	250
E. .	Heigert's White ..	20	20–30	30–40	60	..	230
E. .	Springhurst	25	30	25–30	40	200	230
E M. ..	Bacchus Marsh ..	25	30	35–40	100	450	550
M ..	Mount Barker .	25	30	30	60	430	450
L.M. ..	Nangeela .	25	30	30–40	90	650	650
	Mansfield	25	40–60	40–60	130	750	750
	Burnerang	25	40–60	40–60	140	400	670
	Merino .	20	30–40	40	..	500	750
	[illegible]	20	40–50	40–50	120	500	880
	Tallarook	15	40–50	40–50	70	550	950
	Bass ..	15	30	30	80	500	750
	Wenigup	10	15–20	20	40	..	400

"Wenigup," than in the other varieties, hence the former varieties showed fewer leaves. By August, the late mid-season varieties, "Mansfield" and "Burnerang," had developed twice, and the late ones, "Macarthur" and "Tallarook," nearly twice the number of leaves formed by some of the early varieties; by mid-September, "Mansfield," "Burnerang" and "Macarthur" had more than three times the leaves of "Wenigup" and "Dwalganup," owing to their larger numbers of runners and laterals; but in this particular year, relative figures were not quite normal because of the unusually dry period. By November, most of the later varieties had six or more times the number of leaves of the now senescent earliest ones. Consequently, the ratio of leaf to dryweight was much higher in the leafy later varieties

It is clear from Table 7, that the rate of leaf production per plant was small up to September, and that the general great increase in growth responsible for the well known "spring flush" in the field, began in mid-September, under Melbourne conditions. Such an increase had been noted about the same time in 1938, and some weeks later, in 1939 Reference to fig. 13, giving the figures for mean soil temperature at 6 inches,

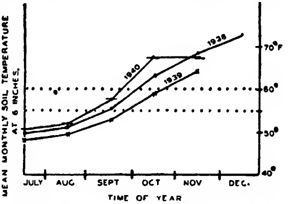

FIG 13—Graph, showing the incidence of the rise in mean soil temperature at 6 inches, in the spring of 1938, 1939 and 1940, at Melbourne.

between July and December, showed that in the three years, the conspicuous increase of growth occurred when the temperature rose from below 55°F. to above 60°F. Thus the incidence of the spring flush may be expected to vary according to the district, because of its particular characteristics of spring temperature levels. Early spring feed thus depends on the possibility of getting a useful increase in leaf production earlier than usual—earlier in September for Melbourne. A closer study of varietal growth during this time should show if any variety has outstanding value in this direction.

1029/41.—9

The dryweight per plant increases with plant development and with the "maturity type" of variety, but varieties within each "maturity type" group differ somewhat in this respect. Table 8 shows that in mid-September, there is little difference in dryweight between the varieties, but by early November, the range between them is wide, and of the two with very early maturity, Mulwala is distinctly superior.

TABLE 8.—INCREASE IN DRY WEIGHT AND BURRS PER PLANT WITH MATURITY, 1937.

Maturity.	Variety.	Date— September 15. Dry Weight. (a)	September 15. Burrs. (b)	November 1. Dry Weight. (a)	November 1. Burrs. (b)	December 16. Dry. Weight. (a)	December 16. Burrs. (b)
		Grams.	No.	Grams.	No.	Grams.	No.
V.E. ..	Dwalganup ..	5	10	8	70	7·5	60
V.E. ..	Mulwala .. .	7	4	20	40	35	100
E. ..	Daliak . .	3	5	9	130	..	..
E. ..	Springhurst .	4·6	0	25	60	27	100
E.M. ..	Bacchus Marsh ..	4·2	0	33	85	35	340
M. ..	Mount Barker	5·3	0	24	16	35	450
L.M. ..	Nangeela ..	6	0	48	6	..	..
L.M. ..	Burnerang	6	0	27	4	50	370
L. .	Tallarook	5·2	0	26	8	60	550
L.	Bass	5·6	0		0	45	220
L. ..	Wenigup	6	0	22	2	70	50

The time at which seed production begins, varies according to the time of maturity of the variety. Table 8 shows that the early varieties had developed several mature seeds by late September, and had finished seed production by November; the mid-season varieties had begun in mid-October and finished in late November, while the corresponding periods for the late ones were in early November and late December. The early cessation of seed formation in the early varieties, in addition to their relatively small capacity for flower production, causes a lower amount of seed formation than in the later maturing varieties. The time taken from germination to the formation of the first burr, gives an indication of the minimum length of growing season necessary for the minimum regeneration of the variety.

EFFECT OF GROWING SEASON ON VARIETAL PRODUCTION.

Investigations by Donald and Smith (10) at the Waite Institute 1935-36 showed that leaf and dryweight production was closely correlated with lateness of maturity, as measured by the time of flowering. The lengths of the growing seasons in the two years of their experiments were 5.5 and 5.0 months respectively owing to late sowing, although the full growing season during these particular years was 8.7 and 7.6 months. They also demonstrated

the importance for seed-setting and maturation, of the daily evaporation from the eighth to the twenty-eighth day after commencement of flowering, and the superiority of "Tallarook" in setting seed under severe conditions. Their investigations were repeated under Melbourne conditions, in order to find the relevance of these results locally. In 1937 it was observed that the date of the appearance of the greatest number of flowers per plant—"maximum flowering"—occurred from four to three weeks later than the opening of the first inflorescence, and this is probably connected with the significance of the evaporation level during the first month after flowering.

Eleven varieties were selected to represent a full range of maturity groups, and several other varieties gave additional data. Observations were taken at the end of the growing seasons of 1937-8-9 on seed-setting, and on the dryweight per plant, excluding roots and burrs (see Table 9).

The plants were sown in the first week of April in the three years during which observations were taken. Seven of the varieties were among those which had been tested at Adelaide. The same order of result was obtained except that the increased number of late varieties studied, showed that the seed-setting of Tallarook was not particularly superior, even under drought conditions.

In 1937, the growing season was somewhat dry (7.6 + months) for Melbourne, and the length of growing season ($^{P}/_{E} > \frac{1}{3}$) beginning from April, was 7.3 months. The dry-weight per plant showed an increase in relation to maturity (col. *a*), in the few varieties tested. The yield of burrs per plant (col. *c*), also increased with length of the vegetation period of the type, but within the early group, the variety "Mulwala" developed more burrs than another early one, "Dwalganup", and among the late varieties, "Tallarook" gave a higher yield than "Wenigup." However, considering the yield of seeds per burr (col. *d*) it is seen that there is comparatively little variation between the varieties, and that if "Wenigup" is excepted as a variety with abnormal inflorescence formation, there is no indication of a lower yield in the later varieties. This lack of agreement with the Adelaide results was thought to be due to the lower evaporation prevailing in late spring. In this particular season, Melbourne weather conditions (6.3 + months) suited the late varieties.

In 1938, a drought year, the growing season was only 5.3 months ($^{P}/_{E} > \frac{1}{3}$) from April, and the spring evaporation was very close to that experienced in Adelaide in 1936. The dry-weight per plant again showed an increase with lateness, but as a result of the dry conditions, the weight per variety was reduced, especially in the later ones, compared with the yield in 1937. The yield of burrs (*c*) was variable, but "Bacchus Marsh" and

TABLE 9.—A COMPARISON OF SEED-SETTING AND DRY WEIGHT PRODUCTION PER PLANT IN THE GROWING SEASONS OF 1937-39, IN VARIETIES RANGING IN MATURITY FROM EARLY TO LATE.

Maturity	Variety.	1937			1938.						1939					
		Dry Weight per Plant (exc burrs or roots)	Burrs per Plant.	Seeds per Burr		Inflorescences per Plant			Seeds per Inflorescence	Ratio of Burrs to Inflorescences						
		a	*c*	*d*	*a.*	*b.*	*c.*	*d.*	*e.*	*f*	*a.*	*b*	*c*	*d.*	*e.*	*f*
V E.	Dwalganup . ..	7 5	60		7	165	25	2 6	0 4	1 6 5	10	170	50	2 8	0 9	1:3 2
V E.	Mulwala .	15	100	2 8	10	285	80	2 7	0 7	1 4	25	460	240	2 6	1 4	1 1 9
E.	Springhurst .	21	100		17	295	50	2 6	0 4	1 6	25	300	90	3 2	0 9	1:3 3
E M.	Bacchus Marsh .	32	340	2 8	22	505	125	3 3	0 7	1 4 8	55	900	450	3 0	1 5	1.2
M.	Mt. Barker .	.	420	2 6	10	340	45	2 4	0 3	1 8	30	1330	590	2 6	1 2	1.2 2
L.M.	Mansfield .		..		30	930	165	2 3	0 4	1 6						
L.M.	Nangeela .	..	..	3 2	34	570	30	2 4	0 1	1 21	50	1130	670	3 0	2 3	1.1 7
L.M.	Burnerang	50	380	2 7	19	195	80	2 0	0 3	1 2 5	30	1250	860	2 8	1 2	1 1 5
L.	Macarthur	..	.	2 7	21	540	65	2 6	0 3	1 8		1580	1500	2 9	2 8	1.1 05
L.	Merino ..			..	29	675	60			1 8		900	.	2 5	.	
L.	Tallarook	60	550	3·2	27	635	95	2 6	0 37	1 7	50	1850	1030	2 8	2 0	1:1 3
L.	Wenigup	70	220	2 1	25	730	41	2 2	0 1	1.1 8	.	550	150	3 3	0 9	1 3 7
L.	Bass . .	..	.	2·8	.				..	.	.	2060	1010	4 0	2 0	1:2

"Mansfield" gave the best yields. Compared with that of the previous year, there was a definite indication of the yield of later varieties being more reduced. However, the yield of seeds per burr (*d*) showed only a slight decrease in most cases. Further data obtained (cols. *d, e, f*), gave more information. A count of the approximate number of inflorescences (col. *d*), produced per plant, showed a general increase with lateness of maturity, but there were large differences between varieties of the one group, e.g. "Burnerang," "Nangeela" and "Mansfield." The Melbourne figures for seeds per inflorescence (which in Adelaide were associated with evaporation), showed that several varieties were poor, compared with the rest, e.g "Nangeela," in the late midseason group, and "Wenigup," in the late group; but there was again no definite trend of low yield with lateness. The varieties "Mulwala," "Bacchus Marsh," "Mansfield" and "Tallarook," appeared somewhat superior to the rest under drought conditions. The figures for the ratio of number of burrs to number of inflorescences (col. *f*) emphasizes the inferior burr-formation of "Nangeela" and "Wenigup".

In this particular season the climatic conditions for Melbourne being similar to the seasons investigated by the Adelaide workers, gave similar results; but the variety "Tallarook" is now seen to have its equals in other late varieties, "Merino" and "Macarthur."

In 1939, a year of abnormally high rainfall, the growing season from April was 8.3 months. All the columns show an increase in yield compared with 1938, especially in cols *e* and *f* The increase is particularly noticeable in the varieties that gave the poorest yields under drought conditions.

The effect of the 1938 and 1939 growing seasons was also shown by the yields of burrs from sample quadrats taken on an established sward of the "Mt Barker" variety. In 1938, the yield from a decimetre square quadrat was 120 burrs, and in 1939, 250 burrs with more than twice the total number of seeds

From the data on varietal flowering and seed production at Melbourne, a tentative table (Table 10) has been drawn up, to indicate the length of growing season necessary for minimum and aggressive regeneration of some of the more important varieties. The figures stated by Trumble for three varieties, are included, and are necessarily somewhat lower because of the higher temperature level available in South Australia for growth in the winter.

It is noteworthy that in 1938, with a growing season of only 5.3 months, ending just before September, both the mid and the late varieties set a fair amount of seed, under spaced plot conditions. Even under sward conditions "Mt. Barker" set as much seed as in the variety plot. It seems likely that, at least in Melbourne, plants can continue growth sufficiently to set seed,

for at least two months after the ratio of precipitation to evaporation has fallen below one-third. This should be tested further in order to define more accurately the effective length of growing season for Southern Victoria.

TABLE 10.—MONTHS OF EFFECTIVE RAINFALL, FOR PERSISTENCE OF VARIETIES IN SOUTHERN VICTORIA, WHEN GERMINATING SECOND WEEK IN APRIL.

Maturity.	Variety.	Months to First Flower	Months to Minimum Seed-setting	Months to Maximum Seed-setting.	Months for Persistence in South Australia (4, 15).
V.E.	Dwalganup	4·5	6·0	7·5	6
V E.	Mulwala	4·5	6·0	7·5	.
E.	Springhurst	4·8	6·0	7·5	..
E.M.	Bacchus Marsh	5 1	6·5	7·8	.
M.	Mt. Barker	5·5	7·0	8·0	7·5
L.M.	Mansfield	5·7	7·0	8·5	.
L.	Macarthur	5·9	7·0	8·5	.
L.	Tallarook	6·2	7·0	8·5 +	8·25
L	Bass	6·5	7·5	8·5 +	..

Summary.

The type variety of the species in Australia—" Mt. Barker," is fully described

Genotypical variation is found to occur in the same characters as occur in such other leguminous species as *Vicia sativa,* and *Pisum sativum.* Fifty varieties are described by means of a table of observed heritable characters.

The characters are grouped as major—those influencing the growth structure, and so the plant's capacity to produce leaves, flowers and seed, and minor—those causing variations in anthocyanin development in leaf, calyx, corolla, stipule, stem, seed and hypocotyl, and hairiness of plant surfaces (leaf, stem, and calyx).

Five major characters make up the "basal runner organization," which is typical for each variety. The characters of number of runners per plant, lateral development, internode length, and seed-production per plant, are all strongly influenced by the time of flowering peculiar to each variety. But, in addition to this influence of time of flowering on productive capacity, there is variation in these major characters within each maturity group, so that choice is possible of the most productive variety for a given length of growing season.

There is indirect evidence that the range of maturity types has not originated under various local conditions within the last 50 years, though there has been some control of the predominance of the early and late maturity types in Victoria, through length of growing season. There is some evidence that minor mutations, changing the anthocyanin development characteristic of a variety, have occurred in Australia.

The time of sowing through the year, influences the length of the vegetative and ripening periods, in the three varieties studied in detail. The time taken for brairding, for flower development, and for ripening, varies in the same order for the three varieties, because of variations in rate of growth due to temperature. The time taken for the rosette period, varies, not only with the rate of growth at a given season, but also according to the variety, and particularly with lateness of variety.

The later the variety, the greater the response of the plant in respect to a lowering of the "node-number," to a summer length of day, applied experimentally. In the field, however, owing to the effect of high temperatures, only for a short period in spring does the increasing length of day hasten flower initiation.

It was found that, in the late variety "Tallarook," flower initiation becomes variable, and then fails, when the minimum weekly temperatures rise above 50°F., and thus the vegetative period suddenly lengthens. The temperature level falls below this in April, but initiation is still prevented, and it is only in late July or early August that plants sown at any time in the previous mid-spring and summer form flower primordia. This failure to commence flower initiation under high temperatures, results in a much longer vegetative period than if variations in rate of growth were the only cause; under conditions preventing summer drought, several months extra grazing can thus be obtained from summer sowings after the critical date.

This may be due, either to a direct repressive effect of high temperature on flower initiation, with a consequent after-effect lasting several months after the temperature has fallen below "critical" level, or to the indirect effect of high temperature, owing to the necessity for a period of low temperature, as a prelude to the formation of flower primordia.

The mid-season variety—"Mt. Barker"—is comparable, except that the critical temperature level is about 53°F., and consequently the first sowing to result in a prolonged vegetative period, is later, and flower initiation is somewhat earlier in the following year—mid-June.

In the early variety, "Dwalganup," sowing throughout the year resulted in flowering all through, but a period of variable initiation occurs from January to March, associated with temperatures fluctuating above a level of about 67°F

In the three varieties, the higher the number of the node at which the first flower is produced, compared with the typical number resulting from an early autumn sowing, the greater the degree of repression of initiation that has occurred.

Varieties sown at the same time, in localities ranging from Launceston to Sydney, showed variations in times of flowering related to the winter-spring temperature level of the locality; the late varieties were the least affected.

In observations on seed-production per plant, in relation to a dry season, certain varieties were superior in each maturity group, and there was no trend of reduced seed setting per inflorescence with lateness.

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APPENDIX I.—DISTRICTS FROM WHICH THE LISTED VARIETIES OF *T. subterraneum* HAVE BEEN OBTAINED.

Variety.	Maturity	Locality of Origin
Dwalganup	E 1	Boyup Brook, Western Australia
Dwalganup White Seeded	E 2	Dwalganup, Western Australia
Mureak	E 3	Mureak, Western Australia
Second Northam	E 4	Northam, Western Australia
Mulwala	E 5	Mulwala, Corowa, Coreen, New South Wales; Quat Quatta, Victoria
Daliak	E 6	Western Australia
Northam	E. 7	Northam, Western Australia
Reigert's White	E 8	Yarloop, Western Australia
Pink Flowered	E 9	Mureak, Western Australia
Yabba North	E 10	Yabba North, Victoria
Springhurst	E. 11	Springhurst, Victoria
Baulkamaugh	E	Baulkamaugh North, Victoria
Seaton Park	E M 1	Seaton Park, South Australia
Bacchus Marsh	E.M 2	Myrniong, Smeaton, Myall, Windermere, Victoria
Burnley	E M 3	Burnley, Victoria
Madrid	E M 4	Madrid, Spain; Leige, France
Milton	E M 5	Milton, New South Wales; Seymour, Sebastopol, Winchelsea, Irrewillipe East, Victoria
Horsham	E M 6	Horsham, Victoria
Hill's Small	E M 7	Cobden, Mount Noorat, Irrewillipe East, Victoria
Samaria	E M 8	Samaria, Benalla, Violet Town, Victoria
Yea	M. 1	Yea, Koriella, Victoria

APPENDIX I.—*continued.*

Variety.	Maturity.	Locality of Origin.
Edenhope	M 2	Edenhope, Goroke, Whitfield, Victoria
Mount Barker	M. 3	Mount Barker, South Australia
Mount Barker White Seeded	M 4	Mount Barker, South Australia
Mount Barker Amber Seeded	M. 5	Mount Barker, South Australia
Red-leaf	M. 6	Upper Lurg, Victoria
Smeaton	M. 7	Smeaton, Victoria
Casterton	L M 1	Casterton, Bendigo, Victoria
Hexham	L.M 2	Hexham, Nalinga, Casterton, Victoria
Mansfield	L M 3	Mansfield, Wangaratta, Docker's Plains, Kyabram, Delatite, Tooborac, Benalla, Victoria
Derrinal	L M. 4	Derrinal, Victoria
Benalla	L.M 5	Benalla, Kyabram, Victoria
Berlin	L.M. 6	Berlin, Germany
Nangeela	L.M 7	Nangeela, Bendigo, Victoria
Kyabram	L.M. 8	Kyabram, Victoria
Burnerang	L.M 9	Wangaratta, Victoria
Pahantamu	L M. 10	Pahantamu, New Zealand
Merino	L. 1	Merino, Victoria
Macarthur	L. 2	Macarthur, Victoria; Bothwell, Tasmania
Ruakura Sein	L 3	Ruakura, New Zealand
Tallarook	L. 4	Tallarook, Seymour, Bena, Korumburra, Romsey, Warncoort, Carisbrook, Warrion, Victoria, Tumbarumba, New South Wales
Wenigup	L. 5	Bridgetown, Western Australia
Rostock	L. 6	Rostock, Cambrai, Europe
Flinders	L. 7	Flinders, Victoria
Wodonga	L. 8	Wodonga, Victoria
Rouen	L. 9	Rouen, France, Berlin, Germany
Phillip Island	L. 10	Phillip Island, Monomeith, Victoria
Kyneton	L. 11	Kyneton, Victoria
Bass	L 12	Bass, Beaconsfield, Tooradin, Mooroolbark, Yering, Glen Alvie, Woolamai, Yannathan, Loch, Monomeith, Caldermeade, Warragul, Bena, Leongatha, Victoria
White Seeded Bass	L. 13	Burnley, Victoria
Ruakura Farm	L 14	New Zealand

APPENDIX II.—KEY TO VARIETIES OF *T. subterraneum* (ADAPTED FROM ULLMANN)

A PETIOLES SHORT TO MEDIUM-STALKED

1 Peduncle little longer or shorter than subtending petiole—

(*a*) Runner mostly 10–15 cm. long, peduncle about as long as subtending petiole, head with 2-5 florets, burr the size of small hazelnut. The most usual form. Variety *genuinum* Rouy, *typicum* Asch & Gr

(*b*) Plant small, runner mostly 3–8 cm long, plant strongly hairy, leaves with felt-like hairs, peduncle much shorter than petiole or almost absent, head with 2–3 florets; burr the size of a pea, calyx often sparsely softly hairy, mostly red coloured, sterile florets with shorter calyx teeth Occasional in dry, stony places Variety *brachycladium* Gib & Belli (2nd Northam) ?

2 Peduncle all or mostly much longer than subtending petiole Plant lax, elongated, runner mostly 25–40 cm, peduncle 4 times longer than petiole; stipules long, pointed, head with 3–5 florets, burr the size of small hazelnut; corolla not noticeably veined. Only in Southern Medit Districts Variety *longipes* Gay (Wenigup ?)

B. PETIOLES OVER 10 CM LONG

1 Plant very vigorous; runner 25–35 cm. long, lax, almost virgate, leaflets large, 2 5 cm long and 3 cm. wide, distinctly toothed, peduncle long, but only as long or shorter than petiole; head with 2–3 large florets; burr the size of a pea, corolla pinkish-striped, calyx teeth ciliate. Mostly in Southern Mediterranean districts, but often more northerly "Plant worth investigation" Variety *oxaloides* Rouy.

2. Like var. oxaloides, but with dark violet flowers, corolla 14–18 mm. long 3–4 times as long as calyx teeth, which are longer than corolla tube Palestine, on light, stony places, occurring with var. oxaloides. Variety *Tel-Avivensis* Eig.

Occurrence of species—British Isles, France, Iberian Penin., Italy, including Islands, Balkan Penin., including Islands, Krun, Caucasus, Asia Minor, Persia, Syria, North Africa, Canary Islands, Madeira.

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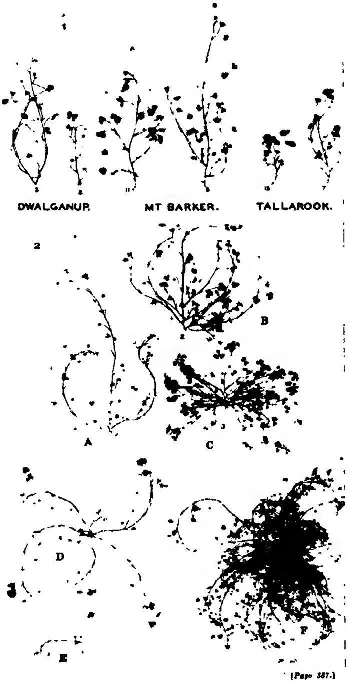

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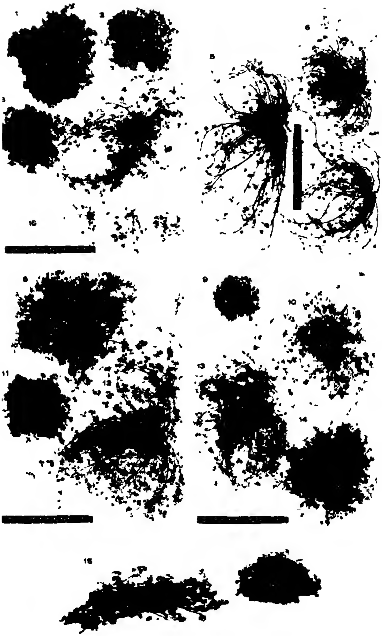

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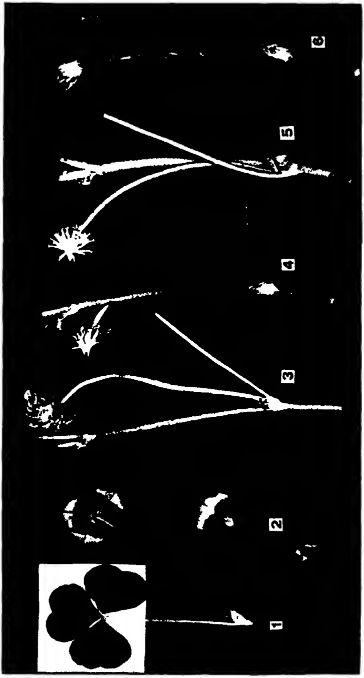
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Explanation of Plates.

PLATE XVII

(1) The effect of exposure to 15 hours daily illumination on plants of Dwalganup (early) Mt Barker (mid) and Tallarook (late) varieties as shown by the node of first flower on the basal runner from each variety A—control B—longday

(2) Basal runners from a plant of Dwalganup (A) Mt Barker (B) and Tallarook (C), to show the increase of laterals developed with increase in number of node of first flower, two plants of Mt Barker variety from a award (D E) and one from spaced plots (F) to show reduction in number of runners and laterals under competitive conditions

PLATE XVIII

Plants of varieties from plots of Burnley Gardens showing range of growth habit in relation to maturity and to variety Sown early April photographed mid October 1 Tallarook 2 Merino 3 Bass (late) 4 Burnley (early midseason) 5 Springhurst 6 Mulwala, 7 Dwalganup (early) 8 Nangeela 9 Burnerang (late mid season) 10 Bacchus Marsh (early mid season) 11 Macarthur 12 Wenigup (late) 13 Mt Barker (standard mid season) 14 Mansfield (late mid season) 15 Plants of Mt Barker (left) and Burnerang (right) photographed at an angle to show the bunched growth of Burnerang compared with the prostrate habit of Mt Barker 16 Plants of Dwalganup Mt Barker and Tallarook sown mid June to show the relatively small size compared with the plants sown in April

PLATE XIX

Some types of pattern on the leaf surface due to variations in anthocyanin and crescent —1 All leaf surface coloured red (Red Leaf) 2 Light green crescent with white arms and a narrow brown edging occurring on some leaves (Seaton Park) Section of stem showing variations in hairiness, 3 glabrous stem peduncle and petiole (Rongert's White seeded) 4 glabrous stem hairy peduncle and petiole (Madrid) 5 hairy stem peduncle and petiole (Mt Barker) 6 hairy stem with appressed hairs (Mureak)

[PROC. ROY. SOC. VICTORIA, 53 (N.S.), PT. II., 1941.]

ART. XIII.—*The Volcanoes of the Portland District.*

By ALAN COULSON, M.Sc.

[Read 12th December, 1940; issued separately 26th July, 1941.]

Introduction.

Underlying the dune sands and dune limestones of the Portland District are extensive basalt flows and tuff beds which represent the western margin of the great Western District lava field of Victoria. These igneous rocks are part of the Newer Volcanic Series, and the lava flows, with a few exceptions, consist of iddingsite-labradorite-basalts of the Malmsbury and Footscray types (Edwards, 1938). The vents from which they were extruded fall into three groups (fig. 1).

The Coastal Volcanoes: Cape Bridgewater, Cape Nelson, Cape Grant, Lawrence Rocks, and Julia Percy Island.

The Central "Sand-covered" Volcanoes. Mt. Kincaid, Mt Richmond, Mt. Clay.

The Northern Volcanoes: Moleside Creek vent, Mt Vandyke, Mt. Deception, the group of vents at Mt. Eckersley, and Mt Eccles

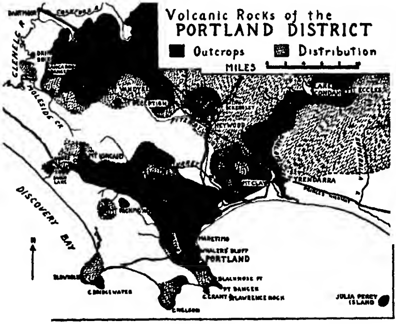

FIG. 1.

Difficulty was experienced in tracing some of the flows to their sources because of the change in texture of the rocks in the vicinity of the vents, and also because of the abundance of tuff associated with some of them.

Coastal Volcanoes.

Cape Bridgewater is a promontory composed of tuffs and basalt flows, overlain by dune sands and dune limestone. The steep eastern cliff-face, which rises to 450 feet above sea-level at the Stony Hill trig. station, provides a section through the composite volcano from which the igneous material came. As shown in fig. 2, two conduits connected with the surface flows of basalt are exposed, one between Bat Cave and Fisherman's Cave, and

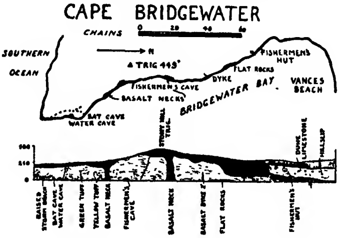

Fig. 2.

the other 30 chains east of Fisherman's Cave. The greater part of the cliff is formed by the undulating beds of tuff, containing scoria and lapilli, of the old volcanic cone. Numerous pebbles of Miocene limestone occur in the lower beds of tuff, but are found only occasionally in the higher beds; and masses of white and pink-stained quartz are embedded in the scoriaceous lava at the top of the vents. These fragments may have been detached from Palaeozoic sediments, which presumably underlie a cover of at least 2,000 feet of Tertiary limestone (as shown by the Portland bore), and probably a certain thickness of Jurassic sediments.

The basalt which was extruded from the more easterly vent, and forms Stony Hill, is dense and black, containing occasional phenocrysts of olivine. These are accompanied by micropheno-crysts of labradorite (An_{60}) and diopsidic augite (2V greater than 45°), and are set in a microcrystalline groundmass of

pyroxene, iron ore, and felspar microlites. The augite tends to be glomeroporphyritic. The basalt from the westerly vent is dark grey, and minutely vesicular. It contains numerous phenocrysts of olivine, some very large, and occasional small laths of plagioclase (An_{60}). Some olivine crystals are unaltered, but others are almost entirely changed to iddingsite. The groundmass is very fine-grained, and consists of minute grains of pyroxene and olivine, felspar microlites, iron ore, and glass. A dyke 2 feet wide occurs at Cowrie Cove. It consists of tachylitic olivine-basalt.

The cliffs forming the western face of the Cape are composed of thick flows of basalt, separated by layers of scoriaceous basalt. Marine erosion has formed "blowholes" in places in the scoriaceous layers. The basalt is dark grey and dense, and consists of numerous microphenocrysts of olivine completely altered to iddingsite, and small laths of plagioclase (An_{60}) in a groundmass of plagioclase laths and abundant brown glass which has a "feathery" appearance owing to the presence of skeletal crystals of iron ore.

The basalt flows from the Cape Bridgewater vents are mostly covered by dune limestone.

Cape Nelson is another composite volcano whose structure is exposed in the cliff section facing Nelson Bay, between Black Bluff and Yellow Bluff (fig. 3). The cliffs rise sheer to a height

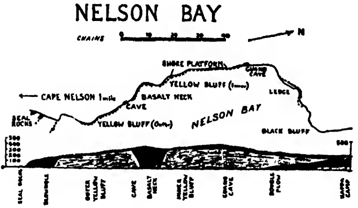

FIG. 3.

of 200–300 feet above sea-level, and are fronted by a narrow wave-cut bench. In the centre of the section is a funnel-shaped vent filled with scoriaceous basalt, and surrounded by beds of yellow tuff. The vent and the tuffs are capped with dune limestone.

At Black Bluff, low down in the projecting cliff face, there are two flows of basalt separated by about 4 feet of tuff. When followed eastwards, the upper flow, which is 5 feet thick, merges into the lower flow, which descends below water level. They are inaccessible, but what is probably the same flow increases in height to the east of Black Bluff, forming a single sheet of basalt about 50 feet thick near Kappa Camp, where it rests on 8 feet of tuff. Here the flow is an iddingsite-labradorite-basalt of the Malmsbury type. East of Kappa Camp, the basalt is cut off, presumably by a north-south fault, and the cliff consists of dune limestone down to sea-level.

This basalt probably had its source in the quarry reserve, Allotment 2, Section VII., Portland, where stone used for the Cape Nelson lighthouse was obtained. The basalt at the foot of the lighthouse (on the "Horseshoe") is also an iddingsite-labradorite-basalt of the Malmsbury type, and extends from the Seal Rocks at Yellow Bluff, to Old Shelly Beach on the west side of Cape Nelson. It is over 100 feet thick, and its base passes below sea-level. Patches of scoria occur in it, and it is overlain by dune limestone.

Cape Grant is of a similar nature. On its western side at "The Wells," four volcanic vents or necks are exposed in the cliffs (fig. 4) which are over 200 feet high. All four have walls of

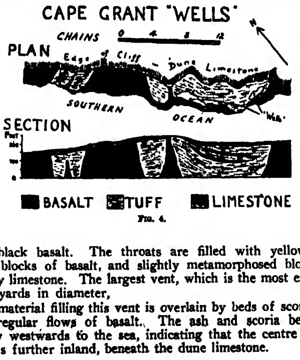

FIG. 4.

dense black basalt. The throats are filled with yellow tuff, scoria, blocks of basalt, and slightly metamorphosed blocks of Tertiary limestone. The largest vent, which is the most easterly, is 150 yards in diameter,

The material filling this vent is overlain by beds of scoria and thin irregular flows of basalt. The ash and scoria beds dip strongly westwards to the sea, indicating that the centre of the vent lies further inland, beneath the dune limestone.

The basalt forming the walls of these vents is dense and black. It consists of occasional microphenocrysts of olivine in part altered to serpentine, in a groundmass of abundant short laths and plates of zoned plagioclase (about Ab_{60}), aggregates of minute augite crystals, square grains of magnetite, and rods of ilmenite

Lawrence Rocks, which are one mile off-shore from Point Danger and project about 80 feet above sea-level, have a basaltic foundation upon which rest beds of yellow tuff about 50 feet thick Wave-cut benches up to 200 yards wide and 3 feet above water-level have been cut in the basalt

Lady Julia Percy Island, 19 miles east of Portland, is a flat-topped island 120 feet high and one and a half miles in diameter, and is composed of boulder tuff, a series of olivine-labradorite-basalts, and iddingsite-labradorite-basalt of the Footscray type (Stach and McIver, 1936) The lava flows were derived from an adjacent vent, part of whose walls remain in the southern cliff of the island (Pinnacle Point).

The Central "Sand-Covered" Volcanoes.

The three domes of lava and tuff forming this group of volcanoes are covered not by dune limestone, but by younger sand dunes

Mt. Kincaid, the most westerly of the three, rises to 664 feet above sea-level, and is covered by patches of dune sand to a height of 500 feet. The summit, which is free of sand, is composed of vesicular basalt The flow from this volcano extends south-eastwards for 20 miles, as far as Portland It is a vesicular, dark-grey, iddingsite-labradorite-basalt of the Malmsbury type. The olivine crystals are of two generations. The earlier-formed crystals occur as idiomorphic phenocrysts and are largely altered to iddingsite, while the later crystals, which belong to the groundmass, are only slightly iddingsitized, indicating that the iddingsitization occurred chiefly prior to the solidification of the lava The flow averages about 100 feet in thickness, and passes below sea-level at Blacknose Point and Point Danger. Dune deposits occur only along its western margin.

It lies chiefly on Miocene limestone, but in the cliffs below "Maretimo" on the Dutton Way (North Portland), at Whaler's Bluff, and in places near Battery Point, an oyster bed, probably of Lower Pliocene age (Coulson, 1940) caps the limestones underneath the basalt. The undulations in the surface of the Miocene beds exposed in the cliffs between Battery Point and "Maretimo" cause the basalt to descend to sea-level nine times in this cliff section, with intervening places where the top of the Miocene is 40 feet above sea-level.

It may be noted that the numerous basalt boulders, up to a foot in diameter, brought up by divers working at the outer end of the long pier at Portland, are derived not from this flow, but apparently from the basalt of Lawrence Rocks. Boulders of this origin are associated with the basalt *in situ* along the beach from Battery Point to Pebbly Beach and Point Danger.

Mt. Richmond, 16 miles west of Portland, is a low broad dome covering an area of 5 square miles and rising to a height of 738 feet. The basalt, which is a fine-grained olivine basalt, is largely buried beneath a thick mantle of dune sands that reaches to the summit, and there do not appear to be any large flows away from the mount, although some may exist beneath the sand. The sands are arranged in a series of "tiers" encircling the volcano. The significance of this feature has been discussed elsewhere (Coulson, 1940).

Mt. Clay, 622 feet above sea-level, is another large dome rising above a basaltic plateau which is 400 feet above sea-level. It is a composite volcano, but all of its several vents extruded a similar variety of dense dark-grey olivine-basalt with a micro-crystalline groundmass. A surface crust of vesicular basalt is present on the southern flanks. Large quantities of tuff were also ejected. A bore near the summit penetrated 130 feet in tuff. This tuff contains occasional blocks of chilled basalt.

On the southern slopes, at the Woolwash, the basalt formed a temporary barrier across the valley of the Surrey River. As a result the present valley of that river is constricted to a bottle-neck between Mt. Clay and the Gorae tongue of the Mt. Kincaid flow. Upstream from this point there has been a development of extensive alluvial flats at Heathmere and Heywood At the base of the alluvium, there is almost everywhere a bed of buckshot gravel which averages 4 feet in thickness and rests directly on the eroded surface of the Miocene limestone. Near the Heathmere Railway Station a bore put down in 1894, in Allotment 2, Section VII., of Bolwarrah, by the Mines Department, passed through 7 feet of alluvium and buckshot, and then entered Tertiary limestone. It was still in Tertiary limestone at 1,505 feet, when it was abandoned.

The Mt. Clay basalt does not appear to pass below sea-level Where its base is exposed it rests on the Tertiary limestones at about 60 feet above sea-level; and on the north side of the Mount, in Section 16, of Narrawong, tachylytic basalt rests on *Ditrupa* limestone (Miocene) at about 60 feet above river level.

The Northern Volcanoes.

Moleside Creek: Volcanic agglomerate outcrops in the great bend of the Glenelg River, near Moleside Creek. The outcrop extends for a mile in an east-west direction, crossing the river at three points, as shown on the geological parish plans of Kinkella and Kentbruck. Between and beyond these points it is

hidden under sand. The agglomerate consists of lapilli, fragments of metamorphosed Tertiary limestone, and fragments of slaggy basalt, which are cemented together by black, vesicular basaltic glass. It rises to a height of 60 feet above river level, and appears to have formed a barrier in the path of the Glenelg, so that it may have been a contributing factor to whatever caused the river to take its great westerly bend at this point. The agglomerate may infill a fissure.

On the south side of the Glenelg in the parish of Warrain, and close to its boundary with the parish of Kentbruck, a basalt dyke 4 feet wide has been noted by the Geological Survey. It is a much decomposed olivine-basalt.

On the west bank of the Glenelg, north of Moleside Creek, a flow of microporphyritic olivine-basalt about 5 feet thick occurs at the base of the dune limestones and sands, and overlies the Miocene limestones, which rise here to 100 feet above river level.

This rock appears to be identical with that capping the Kangaroo Range on the eastern bank of the Glenelg at a height of 400 feet. This similarity, and the difference in level of the two outcrops suggests that in this part of its course the Glenelg follows a north-south fault, as postulated by Foster (1929) in a section accompanying his geological map of the parish of Balrook, though this section does not agree with that drawn by Keble (1928) for the adjacent parish of Drik Drik to the north. Keble shows the "fault" as a cliff section. Foster based his section on the evidence obtainable at a large sink hole in Allotment 35, parish of Balrook. On the east side of the sinkhole, the Kangaroo Range basalt is exposed overlying Miocene limestone, while on the west side there is a boulder bed surmounted by dune limestone which dips at 30°N. and is about 55 feet thick. It rests unconformably on the boulder bed which is at least 20 feet thick. The boulders consist of sub-angular blocks of decomposed basalt, up to 12 inches in diameter, and angular blocks of Tertiary limestone up to 3 feet in diameter. The limestone is indurated, but does not appear to be volcanic ejectamenta. The blocks occur in a reddish-brown sand which contains only Miocene fossils Mr. W. J. Parr has identified the following foraminifera from the sand:—

Dentalina inornata d'Orbigny
Lagena sp. aff. *orbignyana* (Segeuza).
Globigerina bulloides d'Orbigny.
Globigerina dehiscens Chapman, Parr and Collins.
Cibicides sp.
Carpentaria rotaliformis Chapman and Crespin.
Elphidium crispum (Linné).
Operculina victoriensis Chapman and Parr.

Mr. Parr searched for, but failed to find, forms common to the dune limestone, such as *Discorbis dimidiatus*. Presumably, therefore, the boulder bed is a pre-dune-limestone talus at the

foot of a cliff of Miocene limestone surmounted by basalt. There is nothing to indicate whether it is talus from a river cliff or from a fault scarp. Exploration of a tunnel-like cave which connects this sinkhole with others 400 yards to the north, shed no light on this point. The cave is 30 feet high and 4 feet wide at the top, broadening to 10 feet at the bottom. A small underground stream runs through it. To the north the tunnel is in Miocene limestone, while to the south it is blocked by fallen blocks of Pleistocene dune limestone.

If the fault exists, as the levels of the basalt flows would indicate, it is presumably post-basaltic but pre-dune-limestone in age.

Mt. Vandyke (Good Hill) is a point of eruption 606 feet high. A flow of felspathic basalt issued from it, and spread out to the north and west for several miles. Its full extent is hidden by thick forest in the parish of Cobboboonee, but it appears to overlie the Kangaroo Range basalt. The rock is a dark-grey colour with abundant large white felspar and olivine phenocrysts, and bears some resemblance to the type of basalt forming the Stony Rises at Pirron Yallock (Skeats and James, 1937). A similar rock occurs at West Gorae, one and a half miles east of Mt. Richmond, in Allotment 15, Section 9, parish of Mouzie, where it forms a separate hill, probably a point of eruption, about 325 feet high. In this section it is an iddingsite-andesine-basalt of the Ballan Type (Edwards, 1938).

Mt. Deception (524 feet) is three miles east of Mt. Vandyke, and the Fitzroy River runs between them. Mt. Deception consists almost entirely of tuff with a few blocks of slaggy basalt. No flow could be traced from it.

The Mt. Eckersley Group of four volcanic hills comprising the Oakbank Estate, north-west of Heywood, shows considerable variation in the structure and composition of the several hills. Mt. Eckersley proper, or Bell's Hill (537 feet) is largely composed on tuff, which is well exposed in an old quarry near the summit. Occasional blocks of finely vesicular basalt occur in the tuff.

Sugarloaf Hill is composed of a grey compact iddingsite-basalt which is exposed in a quarry in Allotment 3, Section 3, parish of Drumborg. The third hill in Allotment 9, parish of Drumborg, north-west of Heywood Cemetery, is composed of a black, vesicular, fine-grained iddingsite-basalt, but the flow which issued from it to the west is not vesicular, and the olivine in it shows no trace of alteration to iddingsite. A coarser-grained iddingsite-basalt occurs in Allotment 7, Section 4, parish of Drumborg, immediately north-west of Heywood Cemetery.

The fourth hill, in Allotment 7, parish of Drumborg, consists chiefly of tuff with an occasional block of chilled basalt.

Mt. Eccles (584 feet) is probably the most recent point of eruption in the area. The flow from it filled a valley running to the sea, and divided the waters of the Fitzroy River and Darlot's Creek from Ettrick to Tyrendarra. In the vicinity of Tyrendarra and Homerton the infilled valley had been eroded in dune limestone (Hills, 1939; Coulson, 1940), so that this basalt is probably of Recent age. Throughout its length it has developed small stony rises and lava blisters, and numerous lava caves occur within it, similar to those described by Skeats and James (1937) in other parts of Western Victoria. In damming back Darlot's Creek, the flow gave rise to the Condah Swamp (Hills, 1939).

Conclusion.

From the foregoing brief descriptions, it will be seen that the basalts of the Portland District have undergone very little differentiation and are generally similar to the undifferentiated basalts of the Newer Volcanic Series elsewhere in Victoria. The eruptions which gave rise to them appear, however, to have produced a much greater amount of tuff than was developed in Central Victoria. In this respect they resembled the eruptions of the Colac-Camperdown District, where tuffs are equally abundant. The period of extrusion seems to have been of considerable duration, extending possibly from the Pliocene (Mt. Kincaid flow) through to the Recent (Mt. Eccles flow).

Acknowledgments.

My thanks are due to Messrs. W. J. Parr and F. S. Colliver for the identification of fossils; to Mr. G. B. Hope for the loan of instruments; to Messrs. F. E. Levy, W. C. Hedditch, B. O. Squire, and the Mines Department, for supplying maps; and to Dr. A. B. Edwards, for help with the petrography.

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[PROC. ROY. SOC. VICTORIA, 53 (N.S.), PT. II., 1941.]

ART. XIV.—*The Crinanite Laccolith of Circular Head, Tasmania.*

By A. B. EDWARDS, Ph.D., D.I.C.

[Read 12th December, 1940; issued separately 26th July, 1941.]

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Introduction.

Circular Head is a prominent feature of the coast of North-West Tasmania well known both on account of its striking shape (Edwards, 1941) and its history. It owes its highly descriptive name to Bass and Flinders, who sighted it in December, 1798. Flinders (1814) describes is as "a cliffy lump, much resembling in form a Christmas cake, joined to the main by a sandy isthmus;" and in the Hobart Town Almanac for 1831 it is referred to as "that curious rock (which) stands like a huge round tower or fortress, built by human hands, which stretching out to sea, as if from the middle of a bay, is joined to the land by a narrow isthmus." It was here that the Van Dieman's Land Company established the first settlement in the North-West, in 1826.

As described elsewhere (Edwards, 1941) the Head is a tied island, joined to the main part of Stanley Peninsula by a Y-tombolo, which in 1826 still enclosed a marshy lagoon. The lagoon has been drained and converted into pasture land. The Head itself is composed of an igneous rock of a type unusual to Tasmania, and specimens submitted to Rosenbusch were described by him as trachydolerite (Twelvetrees, 1902).

Circular Head appears to be the remains of a small, steep-sided laccolith. As its name indicates, it is more or less circular in plan, with diameters between 800 and 900 yards. It consists of gigantic columns of igneous rock, 4 to 6 feet in diameter, and rising vertically to a height of 487 feet above sea-level. These columns are exposed in sheer cliffs, several hundred feet high, notably on the northern and south-eastern sides, with a fringe of steeply sloping scree around their bases. Inspection of the sea-bed from the top of the cliffs shows that a dark fringe of scree forms a ring of uniform width round Circular Head on all sides exposed to the sea, and no extension of the igneous rock exists

in any of these directions. Similarly, on the landward side where the scree slopes are more gentle, because they are not so subject to erosion, there is clearly no continuation of the rock towards the main ridge of Stanley Peninsula.

On the north-western side, on the beach below the Stanley Cemetery, the scree overlies soft mudstones and grits, which are exposed in the wave-cut bench. These sediments, which are presumably of Permo-Carboniferous age, judging by their texture and disposition, dip at about 30°N, and underlie the whole of Godfrey's Beach, since they also occur in the wave-cut bench at the north-western end of the beach Similar sediments outcrop on the southern side of Circular Head, between the old wharves and the new, where they are visible at low tide. Much weathered sediments overlain by scree deposits are exposed in a cutting opposite the Harbour Master's Office, at the entrance to the wharves; and behind the adjacent timber yard, where the talus deposits have been completely removed, and a quarry has been cut to provide extra platform space, the sediments are exposed as an uneven surface sloping down towards the north-east beneath the igneous rock The contact appears to be more or less conformable, while the sandy sediments are very little metamorphosed beyond induration for a few inches below the contact

At the contact, and for a few feet above, the igneous rock is chilled, and has an almost glassy texture. When followed upwards, the grain size increases, and the ferro-magnesian minerals, particularly the pyroxene, become more prominent At a height of 100 to 150 feet above the chilled base, the pyroxene crystals are 2 to 3 mm in diameter, and show a distinct concentration. They project on weathered surfaces, and give the rock a spotted appearance Rising still higher up the columns the coarse grain size is maintained, but the proportion of pyroxene decreases, until near the top felspar appears to be the dominant constituent. This progressive change can be observed on all sides of the Head

The upper surface of the headland is not flat, as appears from a distance, but slightly undulating. Two small valleys combine to form a hanging valley 80 feet deep, and 320 feet above sea-level, on the southern side.

It is presumed, therefore, that Circular Head represents the core of a small, dome-shaped laccolith. Subaerial erosion has removed the roof and wall rocks, and destroyed the original chilled top of the laccolith. Marine erosion of the soft Permo-Carboniferous sediments underlying the laccolith has undermined the floor of the laccolith around its margins, causing the igneous columns to collapse. In this way the walls of the remaining portion of the laccolith have steepened and increased in height as they have retreated. The undermining process must have begun subsequent to the extrusion of the Green Hills basalt flow which

forms the main ridge of the Stanley Peninsula, and is still in progress. The various stages in the development of the headland are shown diagrammatically in fig. 1.

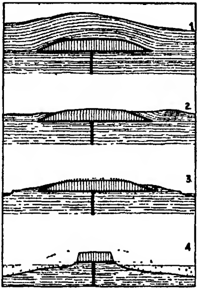

Fig. 1.—Diagrammatic representation of the development of Circ Head 1 Intrusion of li lith; 2. Unroofing, 3. Subaerial erosion, 4 Present stage, after undercutting by marine erosion.

Petrology.

The differentiation noted in the field is readily apparent when the proportions of the ferro-magnesian and other minerals in a series of specimens taken at successive levels from top to bottom of the laccolith are compared by micrometric analyses of thin sections (see Table I.).

TABLE I.—VARIATION IN MINERAL COMPOSITION WITH HEIGHT ABOVE CHILLED BASE.

Height Above Chilled Base	Olivine	Pyroxene	Iron Ore.	Felspars, Groundmass, &c.
Feet.	Per cent	Per cent	Per cent	Per cent
440 (summit) ..	6·8	13·9	3·8	75·4
420	6·4	13·1	3·9	76·6
390	4·4	16·2	3·6	75·8
350 ..	15·7	20·7	4·5	59·0
320	11·8	14·1	4·0	70·1
290 . .	14·7	17·9	3·8	63·6
230	10·9	17·7	4·7	66·7
180 .. .	14·1	18·2	4·0	63·7
130	6·5	27·3	4·0	62·1
100	21·1	18·6	3·0	57·3
70	24·9	21·5	4·2	49·4
20	17·6	15·9	4·0	62·6
0 (base) ..	11·5	0·5	Nil	88·0

Comparison is aided by plotting the mineral percentage against elevation above the contact of the chilled base with the sediments, as has been done in fig. 2A. This shows that there is a marked concentration of the ferro-magnesian minerals in a narrow zone immediately above the "floor" provided by the chilled base of the laccolith. Above this zone the ferro-magnesians decrease steadily with increasing height above the "floor." The concentration of the ferro-magnesians in the lower part of the laccolith has displaced the felspathic and felspathoid constituents into

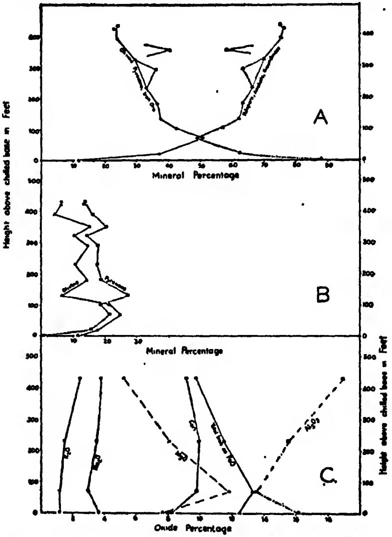

FIG. 2.—Variation profiles of the Circular Head Laccolith. A and B, Mineral Profiles; C, Oxide Profiles.

the upper levels. In fig. 2B, the ferro-magnesian graph of fig. 2A is analysed in terms of the two chief mafic components, olivine, and pyroxene. The olivine had commenced to crystallize prior to the emplacement of the magma, as is shown by its presence in the chilled base, whereas the pyroxene had not. As a result, the accumulation of olivine on the "floor" began before the pyroxene began to accumulate. Moreover, although the earlier-formed pyroxene formed as phenocrysts, and tended to sink, the later-formed pyroxene tended to form ophitic intergrowths with the plagioclase. This had the effect of buoying up such pyroxene. Some olivine, also, was prevented from sinking by becoming enclosed within the ophitic pyroxene. As a result, the gravitation of the pyroxene was less complete than that of the olivine, while the level of greatest accumulation of pyroxene extends above the level of greatest accumulation of olivine, and is not so sharply defined. Further, the sinking of the ferro-magnesian minerals did not proceed uniformly throughout the laccolith As shown in fig. 2A, in some specimens the ferro-magnesian content greatly exceeds the general tenor of the surrounding rock, no doubt as a result of the "buoying up" factors noted above. In others, in which there is an unusual concentration of analcite (Table III.), there has been excessive removal of the ferro-magnesians probably because viscosity was reduced by the presence of abundant mineralizers A number of other factors, such as the effects of convection currents close to the walls of the laccolith, may have contributed to these local variations.

The differentiation within the laccolith is equally well demonstrated by a series of chemical analyses of specimens from various levels, as is shown by Table II., and fig. 2C.

TABLE II—CHEMICAL ANALYSES AT VARIOUS LEVELS IN THE LACCOLITH.

—	1.	2.	3.	4	5.
SiO_2	44·75	43·35	45·70	46·15	48·06
Al_2O_3 . .	16·15	13·50	15·52	18·96	21·33
Fe_2O_3 .	4·52	2·62	3·75	3·68	4·60
FeO .. .	8·35	10·94	8·14	6·41	4·96
MgO	7·68	11·84	8·04	5·20	2·08
CaO	8·20	9·55	9·96	9·15	6·10
Na_2O .. .	3·68	3·02	3·51	3·79	5·18
K_2O . ..	1·18	1·15	1·51	2·43	4·28
H_2O .. .	0·25	0·15	0·19	0·20	0·20
H_2O	1·74	0·71	0·70	1·49	1·72
CO_2	Nil	Nil	Nil	Nil	Nil
TiO_2	2·25	2·25	2·35	1·65	1·96
P_2O_5	0·71	0·63	1·06	0·50	0·25
MnO_2 . ..	0·11	0·10	0·10	0·10	0·12
	99·57	100·34	100·54	99·70	100·77

1. Chilled base at contact, behind timber yard, main wharf.
2. Olivine-rich layer, 70 feet above chilled base, same locality.
3. Two hundred and thirty feet above the chilled base, north-western side.
4. Summit, at 487 feet, or 440 feet above chilled base.
5. Nephaline-rich phase of the crinanite, not *in situ*.

ANALYST. A. B. EDWARDS.

The magnesia content of the analysed specimens shows a sharp increase in the olivine-rich layer, and then decreases in the higher layers. Total iron behaves similarly, though the change from specimen to specimen is not so large. The variation in lime content is more complex in that whereas some lime was carried downwards by sinking of pyroxene, some lime was also carried upwards by the displacement upwards of the plagioclase in the residual magma. This movement of the plagioclase is brought out more clearly by the changes in the alumina and alkali content. These are more or less reciprocal to the changes in magnesia content

The nearest approach to the original magma from which the Circular Head laccolith was derived, is provided by the little differentiated chilled base, and the chemical analysis of this phase (No. 1) indicates that it was a fairly typical undersaturated olivine-basalt magma (in the sense of Kennedy, 1933). The analyses closely resemble those of crinanites, except that they contain rather more potash (Walker, 1934). The potash content is not great enough, however, to enable the rock to be classified as teschenite, nor is the soda sufficiently high for this.

Petrography.

CHILLED BASE.

The chilled base at the contact with the underlying sediments is an almost cryptocrystalline rock, consisting of idiomorphic microphenocrysts of olivine, 0.1 to 0.2 mm. in diameter, set in a groundmass of minute grains of iron ore, olivine, prisms of pyroxene, microlites and minute twinned laths of plagioclase, needles of apatite, and abundant colourless glass. The olivine is partially altered to iddingsite, leaving a core of unaltered olivine, and a narrow rim of fresh olivine encloses the iddingsite. Where the olivine occurs as a groundmass constituent it generally encloses a minute core of iddingsite. Occasional microphenocrysts of moderately violet titanaugite occur, usually smaller than the olivine crystals. The bulk of the pyroxene, however, is present as minute violet prisms in the groundmass. These show extinction angles up to 45 degrees on the prism axis, and are presumably augite. The felspar microlites show practically straight extinction, while the laths with lamellar twinning extinguish at angles up to 15 degrees in the symmetrical zone. This indicates that the plagioclase is a basic oligoclase, of composition about Ab_{70}, which is borne out to some extent by the high soda content of the analysis of this rock (Table II., No. 1). Presumably the colourless glass also approaches this composition.

The most striking feature in the thin sections is the occurrence of numerous almost circular vesicles, 0.1 to 0.2 mm. in diameter, filled with acicular growths of what appears to be natrolite.

Twenty feet above the actual contact, the appearance of the rock has changed greatly. The olivine microphenocrysts average about 0.5 mm. in diameter, although some are as long as 1 mm. They have gathered into clots, and while they retain something of their original idiomorphic outline, they tend to be rounded and embayed. The iron ore grains are fewer, but coarser, and are associated with the clusters of olivine crystals. The interspaces between the clusters of olivine and iron-ore are divided up by long narrow plagioclase laths (averaging about 0.5 x 0.02 mm.), and sometimes larger (1.0 x 0.2 mm.), and the triangular interspaces between the laths are filled with prisms of violet-brown pyroxene, frequently gathered into rosettes or stellate groups. Patches of analcite, sometimes enclosing acicular natrolite, also occur in these interspaces. The plagioclase laths show extinction angles up to 30 degrees in the symmetrical zone, so that they consist of labradorite, of a composition about Ab_{45}. Even the apatite needles have partaken of the general increase in grain size.

THE OLIVINE-RICH LAYER.

The rock composing the layer of olivine accumulation, about 70 feet above the chilled base, shows a further change in texture. The titanaugite crystals have grown in size to prisms 0.5 x 0.2 mm. and have gathered into clusters, often preserving the stellate arrangement observed in the more crystalline part of the chilled base. In these clusters the titanaugite crystals are usually associated with the numerous coarser-grained, but rounded, crystals of olivine, and relatively coarse-grained crystals of iron-ore. Very little pyroxene remains in the groundmass, which consists essentially of plagioclase laths, crowded together, a little interstitial orthoclase, and analcite. The plagioclase is a basic labradorite (Ab_{45}), and has suffered partial analcitization. The individual laths are relatively small compared to the other minerals. The analcite in some of the interstices is intergrown with numerous more or less radially arranged inclusions of a purplish to brownish substance, which is generally opaque, and gives the impression of being extremely thin plates of titaniferous iron ore. Some of the brown inclusions, however, are very weakly birefringent, and show a minute cleavage pattern similar to that in the pyroxene, suggesting that it consists of thin plates of pyroxene. Some of the intergrowths are more or less granophyric in appearance.

At 100 feet above the chilled base the rock is essentially similar. The olivine, however, has undergone partial iddingsitization, and a wide rim of fresh olivine encloses the iddingsitized portion. The junction between the iddingsite and the outer olivine is sharply defined, but where cores of olivine are also present, the junction of the iddingsite with this inner olivine is fibrous and irregular. The felspar is still restricted to the groundmass, and

is chiefly basic labradorite (Ab_{35}), but a small amount of interstitial orthoclase is also present. The apatite crystals have become noticeably coarse-grained, and appear as hexagonal cross sections and as large prisms.

ANALCITE-OLIVINE-TITANAUGITE-DOLERITE.

The bulk of the laccolith, the upper 320 feet, is composed of analcite-olivine-titanaugite-dolerite, in which the proportion of olivine decreases with elevation above the chilled base. In the uppermost 100 feet the olivine constitutes less than 10 per cent. of the rock, except in localized patches, and the titanaugite, which is the dominant ferro-magnesian, becomes increasingly ophitic towards the plagioclase, so that in the uppermost 50 feet of the laccolith the rock may be regarded as a true crinanite. Its richness in potash, however, reveals affinities with the teschenites.

The chief distinction between the dolerite and the olivine-rich layer is the increased coarseness of grain-size in the dolerite. Individual crystals of olivine and titanaugite frequently attain a diameter of 2 mm. or even larger, and the plagioclase laths show a comparable growth in size. The olivine has frequently undergone partial alteration to iddingsite, and consists of a core of olivine, mantled by a zone of iddingsite, which is enclosed in turn by a narrower rim of fresh olivine. The outer junction of iddingsite and olivine is sharply defined, but the inner one has a fibrous character, as in the upper part of the olivine layer. The titanaugite is distinctly pleochroic, with X — yellow, Y — deep violet, Z — pale violet, and has a (+) 2V about 60 degrees. The large crystals are frequently zoned, the marginal zones being a deeper violet than the inner ones. They sometimes show twinning and hour-glass structure. The titanaugite tends to enclose the smaller olivine crystals, and this habit becomes more marked with increasing height above the base In some instance the olivine so enclosed has been completely altered to iddingsite, presumably prior to its enclosure by the titanaugite. The ferro-magnesian minerals and the iron ores have segregated into clusters, and the plagioclase laths form a triangular pattern in the interspaces. The plagioclase is basic labradorite (Ab_{35}). Patches of interstitial orthoclase are associated with it, and these appear to grow larger and more numerous near the top of the laccolith.

The proportion of analcite varies irregularly. It occurs in the interstices between the plagioclase laths, and frequently invades the plagioclase along cleavage planes and cracks. Where it makes contact with crystals of titanaugite there is a tendency for a narrow partial rim of aegirine-augite, or even aegirine to develop. Radial intergrowths of brown and purplish material such as were noted in the olivine-rich layer continue to be present in the analcite, and the coarse apatite prisms become a prominent feature in the sections. Sometimes, either owing to irregular crystallization or to partial resorbtion they form " atoll " growths.

Soda-rich Variations.

Although no variety more soda-rich than the crinanite of Analysis No. 4, Table II., was observed *in situ*, a number of lighter coloured boulders were observed in the screes and the beach deposits on either side of Circular Head. Specimens of these boulders proved to be much more sodic than the normal rock, and were found to contain notable amounts of analcite, and natrolite, and even a little nepheline.

The ferromagnesians form only a small part of these specimens. Olivine is subordinate to titanaugite, and both are present only as small crystals. The olivine is often enclosed in the pyroxene, and consists of a core of iddingsite enclosed by fresh olivine. The titanaugite has a (+) 2V about 60 degrees, and is invariably ophitic towards the plagioclase (Ab_{40}), which tends to occur in clusters of long narrow laths separating areas in which they are intergrown with the ferromagnesians. The titanaugite is commonly altered at the margin to a narrow rim of aegirine. Analcite is prominently developed, and has attacked the plagioclase to a considerable extent, but has not affected the orthoclase, which occurs relatively abundantly in the interstices of the plagioclase areas. Natrolite forms acicular growths in elongated and irregular-shaped areas of a vesicle-like character, and occasionally a corroded crystal of nepheline, preserving much of its idiomorphic outline, is present. Coarse prisms of apatite are numerous in association with the analcite and natrolite.

Nepheline-rich Phase.

A specimen still richer in soda occurs in the collection of the Geological Survey of Tasmania (No. 288). Chips of this specimen sufficient for analysis were placed at my disposal through the kindness of Mr. F. Blake, Acting Government Geologist of Tasmania, and the analysis is shown in Table II, No. 5, from which it will be seen that not only soda, but potash also, is concentrated in this specimen.

The rock has a greyish, weathered appearance in hand specimen, and is spotted with small irregular-shaped areas of zeolites, occasional porphyritic felspars 5 mm. long, and laths of pyroxene. On roughly polished surfaces it shows spherical intergrowths of radially arranged felspar and titanaugite. Thin sections reveal occasional small crystals of olivine, extensively altered to iddingsite and iron ore, but preserving their idiomorphic outline to some extent. The dominant ferromagnesian, however, is titanaugite, which occurs chiefly in relatively small crystals, and also forms graphic intergrowths with the analcitized plagioclase. It frequently shows a passage through aegirine-augite to aegirine at the margin. The aegirine rims are often as wide as the titanaugite core, and the transition zone is marked by precipitated iron ore. Individual crystals of aegirine also occur through the

rock, though in much less abundance than the titanaugite. Plagioclase and orthoclase are present in more or less equal proportions. The plagioclase is labradorite (About Ab_{48}), and tends to occur as clusters of radially arranged laths. The orthoclase occurs as clear, broad areas filling the intersertal spaces and enclosing most of the other minerals. As shown in Table III. below, analcite and natrolite constitute about 16 per cent. of the rock, while nepheline forms about 8·5 per cent. of it. The nepheline occurs in numerous large rectangular and hexagonal crystals, which are somewhat corroded, and are veined by the analcite. It readily takes a stain with methylene-blue, using the method described by Shand (1939), but is not zoned. Coarse crystals of apatite, almost large enough to be classed as microphenocrysts, continue to be numerous, and the doubtfully identified brown to purplish material, found intergrown with the analcite throughout the laccolith, is also present. A little brown to emerald-green glass is also present, but iron ores are few, though coarse-grained. A micrometric analysis of several sections gave the following approximate composition:—

TABLE III

Mineral.	Volume
	%
Nepheline	8·6
Analcite, &c.	16·1
Plagioclase	34·8
Orthoclase	30·0
Titanaugite	4·6
Aegirine	2·8
Olivine	2·6
Iron ore	0·5
	100·0

Differentiation Processes.

The chief factor operating in the differentiation of the Circular Head laccolith appears to have been the differential sinking of the ferromagnesian minerals under the influence of gravity. The concentration of plagioclase in the upper levels was due to the reciprocal displacement upwards of the residual liquid by the sinking ferromagnesians.

The local concentrations of alkali-rich minerals call for a different explanation. The presence of corroded nepheline crystals, interstitial orthoclase, and titanaugite altered to aegirine proves that the concentrations of alkalis developed prior to complete solidification, though much of the analcite and natrolite may be of autopneumatolytic origin. Since the orthoclase occurs through the laccolith in minute interstitial patches, as one of the

last minerals to crystallize, it is presumed that these local concentrations of alkaline minerals represent small pockets of the final residual liquid of the magma trapped in the otherwise more or less solidified mass. It may be noted in this respect that the plagioclase in the most rapidly chilled part of the laccolith base has the composition of oligoclase (Ab_{70}), while the plagioclase throughout the more slowly cooled part of the laccolith is labradorite (Ab_{88-48}). Hence, although sufficient soda (and potash) was present to convert the bulk of the labradorite to oligoclase, it failed to enter into the composition of the plagioclase. Instead it made its appearance as analcite, and so far as it was not all used up in this mineral, it must have entered into the final residuum of the magma.

The richness of the magma in mineralizers indicated by the abundance of analcite provides an explanation of the unusual occurrence of iddingsite. Previously iddingsite appears to have been recorded only from extrusive and hypabyssal rocks (Ross and Shannon, 1925). Its mode of occurrence is closely comparable with that of iddingsite formed during the actual process of extrusion in certain Victorian basalts, where a temporary concentration of mineralizers led to formation of iddingsite, with a subsequent reversal to olivine precipitation when the mineralizers were exhausted (Edwards, 1938). In both instances the iddingsite shows a fibrous reaction junction with the olivine which it replaces, but has a sharply defined junction with the rim of olivine that surrounds it, indicating a sudden cessation of reaction and return to the formation of olivine. Since the formation of iddingsite requires oxidizing conditions and the presence of abundant mineralizers, it must be assumed that such conditions were brought about in the laccolith by the relief of pressure that accompanied the doming up of the sedimentary roof

Similar Occurrences in North-West Tasmania.

Two other laccoliths of analcite-olivine-dolerite occur along the coast of North-West Tasmania. One is the hill known as Mount Cameron West, which lies about 4 miles north of Marrawah, and rises to a height of about 200 feet. This striking hill is a "resumed island" (Edwards, 1941) It has suffered rather more irregular erosion than Circular Head, but in profile it preserves its dome-shape. Erosion at the seaward side has converted that part of the laccolith into a sharp crested ridge. At its eastern end, however, it retains its broad flattish top, which gives place to steep slopes on all sides. Close to sea-level, where it overlies flat-lying (?) Permo-Carboniferous sediments it has been chilled to a fine-grained olivine-basalt. Above this it becomes coarser-grained, but the thickness of the laccolith was not great enough to permit very much differentiation.

The other is the much larger laccolith of Table Cape near Wynyard, which is known to consist of rocks which are microscopically identical with those forming the Circular Head laccolith (Twelvetrees, 1902).

Age Relations.

The age of the Circular Head laccolith cannot be established with any certainty. It is older than the adjacent basalts of the Stanley Peninsula, because these were extruded in a valley that passes below sea-level, so that the valley bottom is at a lower elevation than the base of the laccolith. The laccolith was largely unexposed at the time of the basalt extrusion, because the Permo-Carboniferous beds enclosing it formed the east wall of the pre-basaltic valley. The top of the laccolith may have been uncovered, in view of the hanging valley situated there The basalts of the Stanley Peninsula are regarded as being of Pliocene age (Nye and Blake, 1938).

At Mount Cameron West there is a similar lack of evidence. A Recent foraminiferal limestone abuts against the laccolith, and there are Miocene limestones in the vicinity, but the relation of the latter to the laccolith is not known. At Table Cape, basalt flows of Pliocene age abut against the laccolith, which had undergone extensive erosion prior to the extrusion of the basalts, and so is considerably older. Stephens (1908) reports that the Lower Miocene beds of Fossil Bluff also abut against the laccolith, but he was unable to say whether or not the contact was an intrusive one. Mr. F A Cudmore, however, informs me that this is not so, and that the Miocene beds pass below sea-level before reaching the laccolith. If the laccoliths are shown ultimately to be of pre-Lower Miocene age they may be linked with the pre-Miocene basalts of Marrawah (Nye and Blake, 1938); and it would be tempting to correlate them with the closely comparable crinanite and olivine-analcite-dolerite dykes of the Older Volcanic Series (Oligocene) in South Gippsland, Victoria (Edwards, 1934).

Acknowledgments.

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ART. XV.—*Note of the Occurrence of Fossiliferous Devonian Tuffs in the Dandenong Ranges.*

By EDWIN SHERBON HILLS, Ph.D., D.Sc.

[Read 12th December, 1940; issued separately 26th July, 1941.]

Introduction.

In December, 1939, while on a visit to Mt Dandenong, I noted with interest the occurrence of fine-grained bedded tuffs, closely resembling certain of the tuffaceous Upper Devonian fish beds at Taggerty, inter-stratified with the dacites on the western flanks of the mountain. Although at the time no fossils were obtained, the probability that these tuffs would prove fossiliferous appeared to be strong, and on a subsequent occasion the excellent sections on the new road from Montrose to Kalorama were examined. Tuffaceous beds were then discovered at two localities, one of which yielded fragmentary carbonized plant remains. These fossils, although unfortunately indeterminate, are of considerable significance in that they indicate with certainty the stratification planes in the beds in which they occur, thus permitting the measurement of dip and strike. The presence of the tuffs also enables the upper and lower surfaces of the adjacent lava flows to be determined, giving precise limits to certain of the flows, which previously it had not been possible to fix.

In view of the significance of the occurrence of the tuffs, a rapid reconnaissance of the western flanks of the main Dandenong Range was made, and further discoveries were made at the localities indicated on the map (fig. 1). Plant remains of a type similar to those on the Kalorama road were obtained from two more places, one on the old road from Montrose to Kalorama, and the other at the Glenfern Quarry at Ferntree Gully. The tuffs were thus shown to constitute an important horizon among the lavas, extending over a distance of seven miles along their strike. They therefore afford an important clue to the structure of the Dandenong Range, the significance of which will be discussed below No attempt, however, has been made at a detailed survey of the district, as a comprehensive study of this and neighbouring areas is being undertaken by another investigator.

The Structure of Mt. Dandenong.

As has been shown by Morris Morris (1914), the Dandenong Ranges and the adjacent country on the north and west are composed chiefly of lava flows, ranging from toscanites at the base of the succession to hypersthene dacite at the top. The lavas are believed to be Upper Devonian in age, for reasons which

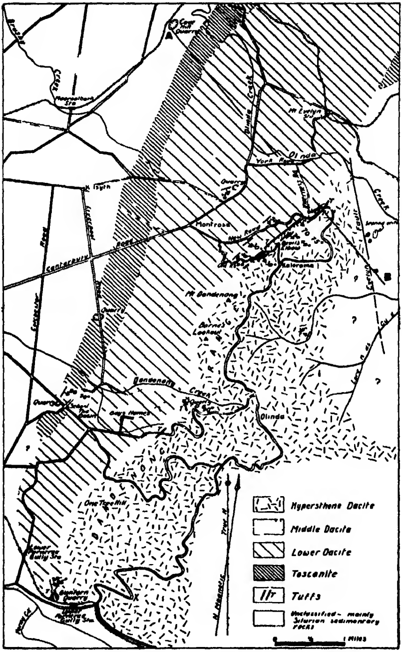

FIG 1.—Sketch Geological Map of the Dandenong Ranges Boundaries mainly after Morris Morris (1914), generalised to reveal trend lines.

have been fully set out in previous publications (Hills, 1931, 1935). Although the newly discovered plant remains have no strict bearing on the age of the lavas, owing to their indeterminate nature, nevertheless they bear a certain superficial resemblance to the plant remains discovered by Hauser in the south Blue Range at Mansfield, these being associated with Upper Devonian fishes (Cookson, 1937; Hills, 1936).

The fossiliferous tuffs on the new road from Montrose to Kalorama are immediately overlain by fresh dacite which exhibits well-marked flow structure. The flow planes, and also the major joints in this dacite are parallel with the stratification planes in the fossiliferous tuffs, and, therefore, must both have been originally horizontal. In the dacite under the tuffs (see detailed sketch map, fig. 2) flow planes are well-marked in places, though elsewhere they are not discernible with certainty. They again indicate the bedding in the lava, but in this rock the major joints have no readily recognizable relationship with the flow planes, usually cutting across them at various angles. It is clear from the sections along this road, however, that for purposes of mapping, the flow planes afford reliable guides to the bedding in the lavas, and that their dip and strike are structurally significant.

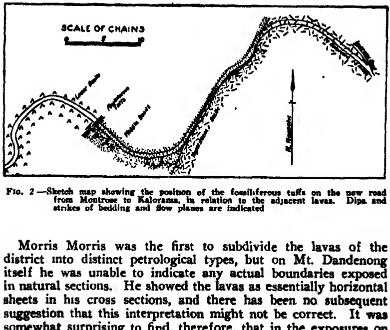

FIG. 2—Sketch map showing the position of the fossiliferous tuffs on the new road from Montrose to Kalorama, in relation to the adjacent lavas. Dips and strikes of bedding and flow planes are indicated

Morris Morris was the first to subdivide the lavas of the district into distinct petrological types, but on Mt. Dandenong itself he was unable to indicate any actual boundaries exposed in natural sections. He showed the lavas as essentially horizontal sheets in his cross sections, and there has been no subsequent suggestion that this interpretation might not be correct. It was somewhat surprising to find, therefore, that in the exposures on the new road the tuffs and lavas are dipping at high angles of from 30 degrees to 75 degrees in a south-easterly direction (see figs. 1 and 2). High dips prevail at and above the fossiliferous

tuffs, but on the lower slopes of the mountain there is a gradual decrease to 30 degrees. In two small quarries about 200 yards above Long View House on the new road a characteristic bed of agglomerate, interstratified with the dacites, dips at 30 degrees in conformity with the flow planes in the lavas, thus justifying the use that has been made of the flow planes in mapping.

Owing to Morris' inability to indicate precise boundaries for the middle dacite, there has been in the past some difficulty in the identification of this flow. The upper (hypersthene) dacite is usually readily distinguishable from the lower lavas, chiefly by its characteristic fine texture, and its base can be accurately located on the new road. At its junction with the underlying flow, which is somewhat undulating but dips on the average at 78 degrees to 80 degrees, there occur fine-grained tuffs which are peculiar in that they not only mantle the surface of the lower flow but also extend into it, isolating lenticular masses from the massive rock beneath, and penetrating along cracks. It is suggested that at the time the tuffs were laid down, the surface of the flow on which they were deposited was cracked and covered with boulders The tuffs entered the cracks, surrounded the boulders, and then, when the hypersthene dacite was extruded and also during subsequent earth movements, shearing occurred in the soft tuffs, the boulders being rolled along and incorporated in them.

The base of this underlying flow immediately overlies the fossiliferous tuffs lower down the road, there being no visible break within the lava between these limits. This flow, then, should correspond with Morris' middle dacite. His mapping agrees with this interpretation, and the petrological characters of the flow correspond closely with his description of the middle dacite. Commencing at the base with a markedly banded type containing coarse and fine layers, the rocks passes up into a facies characterized by numerous large plagioclase phenocrysts with subordinate quartz and biotite, while at the top the phenocrysts are rather smaller, quartz increasing in amount. The nature of the groundmass, shimmering with small flakes of pale-brown biotite, was also commented on by Morris. There can be no doubt, therefore, that this flow, between the precise limits indicated, constitutes the middle dacite as defined by him.

Conforming with this interpretation, the petrological characters of the lavas immediately below the fossiliferous tuffs agree with Morris' description of the lower dacite. This series contains garnet in fair amount, and possesses a granular quartzo-felspathic groundmass with phenocrysts of quartz, plagioclase, and biotite. It is notably fragmental in places, the occurrence of bedded agglomerate at the small quarries referred to above indicating that it consists of more than one flow. The base of this series was accurately located by Morris at several points, and its top is now shown to be at the fossiliferous tuffs on the new road.

On the basis of the reconnaissance survey that has been made, a provisional sketch section showing the structure between Mt. Dandenong and Lilydale may be drawn (fig. 3). While the areal mapping of Morris and observations of flow planes in the lavas indicate the structure of the country to the west of the base of the hypersthene dacite with some degree of accuracy, the interpretation of the eastern part of the section is not easy. Reliable measurements on flow planes in the hypersthene dacite are difficult to obtain, but there is a suggestion in the field, which is to some extent borne out by physiographic evidence, that the dips decrease rapidly towards the east, as they certainly do to the north of York Road. Morris' mapping (1914, Pl. XXX.), shows clearly that in the Lilydale and Mt. Evelyn districts, the general structure of the lavas is that of a broadly open syncline, flanked by the toscanites on the west, north and east. South from Evelyn, however, the eastern boundary is shown by him as the Evelyn Fault, and as will be clear from fig. 1, there can be little doubt that the country to the west of this fault has been downthrown, the steeply-dipping lavas on the northern flanks of Mt. Dandenong being truncated along the line of the fault. The southerly extension of the Evelyn Fault, and of the synclinal structure referred to in the north, is however quite uncertain at present.

Fig 3.—Geological section along the line A-B on Fig 1

The thickness of the various flows in this district is, as may be seen by comparing fig. 3 with Morris' cross sections, much greater than was formerly thought. The middle dacite is approximately 700 feet thick on Mt. Dandenong, and the lower dacite series of the order of 4,000 feet, the precise values not being determinable without further detailed mapping of boundaries and flow planes

Structure of the Southern Area.

In traversing south from the new Montrose-Kalorama road, the dips are at first found to decrease somewhat from the high angles of 70 degrees to 75 degrees observed further north, and angles of from 30 degrees to 40 degrees are common. In the disused quarry on the road to "Doongala" near the head of Dandenong Creek, however, pyritized tuffs occur dipping at approximately 90 degrees, although about three-quarters of a mile further

south, on the road from the Basin to Olinda, the dip is apparently much lower, reliable readings on bedding planes not being obtainable. In the Glenfern Quarry at Upper Ferntree Gully, excellent exposures are available, and the occurrence of fossils again removes all doubt as to the attitude of the bedding planes. The fossiliferous tuffs strike at N. 20 W., and dip at 80 degrees in a westerly direction. In all other parts of the quarry, however, flow planes and bedding planes dip at 70 degrees to 80 degrees in an easterly direction, so that it would appear that the plant beds are locally overturned. On the eastern side of the quarry, fine-grained bedded tuffs form massive beds that have been indurated and pyritized, pyritization of the tuffs being also noted at the two localities near Dandenong Creek, above referred to. There are at least two distinct horizons of tuffs in the quarry, and it is, therefore, obvious that several lava flows are present There is a wide range in the texture of the flows, from dense blue-black types with scattered phenocrysts of quartz, plagioclase, and garnet, to coarsely crystalline saccharoidal varieties. All, however, show a close resemblance to the lower dacite series at the northern end of the range, and the occurrence of interbedded tuffs at the Glenfern Quarry substantiates the conclusion above arrived at that the "lower dacite" is a composite series consisting of interbedded lavas, tuffs, and agglomerates

In the southern area, the toscanites at the base of the lava succession, as well as the overlying dacites, are steeply dipping. This may be seen in the small quarry near the Basin, where the toscanite is nearly vertical. High dips are thus an essential feature of the main Dandenong Range in a zone extending from Ferntree Gully to Mt. Dandenong, and this discovery affords an adequate structural explanation of the very steep slopes that are characteristic of the western flank of the Dandenong Range. The range is indeed an asymmetrical hogback, with a number of high points such as Mt. Dandenong, Barnes' Lookout, and One Tree Hill, all in hypersthene dacite, on its summit. On the east, however, the hypersthene dacites form a maturely dissected plateau only slightly lower in general elevation than the summit of the main range. This suggests, as above indicated, that the dips may flatten in this direction Reliable measurements on flow planes could not, however, be obtained in the hypersthene dacite in this district.

Conclusion.

The present investigation has implications concerning several controversial questions of local geology. Firstly, the hypothetical Dandenong Fault, postulated with reservation by Jutson (1911) as bounding the Croydon Lowlands on the east is, as has been previously argued (Hills, 1934), a purely erosional feature. Actually, as was previously concluded on purely physiographic grounds (Hills, 1934, p. 160; 1940, p. 253), the lavas of the Dandenong Range owe their preservation to having been

originally depressed within the crust by folding, possibly aided by ancient faulting, and their present topographic elevation is due to their resistance to erosion. In this regard, the views expressed by Morris Morris (1914, p. 359) were essentially correct, although he regarded the depression of the lavas as being due to their downfaulting between a hypothetical Montrose Fault on the west and the Evelyn Fault on the east. Morris postulated the Montrose Fault because of the rectilinear nature of the junction between the toscanites and the lower dacites. This junction, it will now be clear, is rectilinear because of the high dips in the lavas, and there is no necessity to postulate the existence of a fault in the position shown by him. The structure, insofar as it can be interpreted at present, is rather that of a great monoclinal fold, the axis of which runs obliquely across the lavas of the ranges, in a S.W.–N.E. direction. This axis, in the north, is itself truncated by the Evelyn Fault, trending from east of south to west of north Along and adjacent to this fault, minor intrusions of granitoid rocks have made their way. In the Ferntree Gully district, however, where the western edge of the lava succession dips at approximately 90 degrees, it may well be that the monocline has passed laterally into a fault, which now separates the Silurian rocks on the west from the Upper Devonian lavas on the east.

In conclusion it may be remarked that the final elucidation of the structure of the Dandenong Ranges, which must await further detailed research, may be expected to have a notable bearing on the Siluro-Devonian tectonics of Victoria, since a Lower or perhaps even Middle Devonian age has recently been indicated for the Lilydale limestone by Dr. Dorothy Hill (1939).

The assistance of Dr. A. B. Edwards in discussions during the preparation of this note is gratefully acknowledged.

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[Proc. Roy Soc. Victoria, 53 (N.S.), Pt. II., 1941.]

Art. XVI.—*Studies in Australian Tertiary Mollusca, Part II.*

By F. A. SINGLETON, D.Sc.

[Read 12th December, 1940; issued separately 26th July, 1941.]

In the nine years since the communication of Part I. of this series, much new material has been accumulated, part of which is dealt with in the present paper, again confined to Pelecypoda, wherein the following new names are proposed and the new species figured:—

Nucula (Ennucula) gricei, sp. nov.
Nuculana (Scaeoleda) killara, sp. nov.
Limopsis werrikooensis, sp. nov.
Glycymeris (Veletuceta) pseudaustralis, sp. nov.
Ostrea sinuata glenelgensis, subsp. nov.
Notochlamys antecedens, nom. nov.
Aulacomya suberosa, sp. nov.

I am again under obligations to the Director, Mr. D. J. Mahony, and the Palaeontologist, Mr. R. A. Keble, of the National Museum, Melbourne, for continued access to the collections housed therein, and for allowing me to describe new species from them. To the late Miss J. Wilson-Smith, Mr. J. S. Mann, and Mr. G Baker, I am indebted in respect to the illustrations.

Class PELECYPODA.

Family NUCULIDAE.

Genus **Nucula** Lamarck, 1799.

Subgenus **Ennucula** Iredale, 1931.

(*Vide* "Studies," Part I., p. 290, 1932.)

This name, proposed as a full genus by Iredale, but regarded only as a section of *Nucula* by the writer (1932, p. 292), may perhaps be accorded subgeneric rank, a course adopted by Schenck (1934, p. 46). It may be noted that in Schenck's revision he has figured from the Arafura Sea (1934, pl. 3, fig. 4) under the name of *Nucula obliqua* Lamarck (the type species of *Ennucula* Iredale) a Recent shell, clearly *Nucula superba* Hedley (1902, p. 292), which occurs in Northern Australia, whereas *N.* (*E.*) *obliqua* is confined to S.E. Australian seas.

Nucula (Ennucula) gricei, sp. nov.

(Pl. XX., figs. 1*a*, *b*.)

"*Nucula tenisoni* Pritchard," Singleton, 1932, p. 292, pl. xxiv., figs. 5*a*, *b*. Not *Nucula tenisoni* Pritchard, Proc. Roy. Soc. Vic., n.s., viii., p. 128.

Holotype.—Shell thin, subovate, very inequilateral, posteriorly somewhat produced, moderately depressed; umbonal angle 140 degrees, anterior margin evenly rounded, posterior margin short, subtruncate; surface mostly smooth, with weak concentric folds towards ventral margin; hinge, slender, gently arcuate, with nineteen teeth, of which three are rudimentary, in anterior and six teeth in posterior series, separated by an oblique anteriorly directed resilifer, interior nacreous, shining, inner ventral margin smooth. Length 14.3; height 10; thickness of valve 3.6 mm

Type Locality.—Grice's Creek, between Frankston and Mornington, Victoria. Balcombian (Middle Miocene ?).

Type Material.—Holotype (Pl. XX, figs. 1*a*, *b*), right valve, coll. and pres. F. A. Singleton, Melbourne University Geology Department Palaeont. Coll., Reg. No. 1311.

The differences from *N. tenisoni* already noted (1932, p. 292), together with the apparent restriction of the present species to the Balcombian stage, to which the writer (1941, p. 73) would now refer the Barwonian localities at which it is found, make advisable its separation as a new species.

Family NUCULANIDAE.

Genus **Nuculana** Link, 1807.

Nuculana Link, Beschr. Samml. Rostock, iii., p. 155, 1807.

Type (by monotypy). *Arca rostrata* Chemnitz = *Mya pernula* Müller. Recent, Northern Europe.

Subgenus **Scaeoleda** Iredale, 1929.

Scaeoleda Iredale, Rec. Aust. Mus, xvii. (4), pp. 158, 187, 1929.

Type (by original designation): *Nucula crassa* Hinds. Recent, S. Tasmania

NUCULANA (SCAEOLEDA) KILLARA, sp. nov.
(Pl. XX., fig. 2.)

Holotype.—Shell small, elongate ovate, moderately depressed, posterior slope flattened, bounded by a marked posterior keel; anterior end rounded, posterior end bluntly rostrate, ventral margin evenly rounded, post-dorsal margin nearly straight; umbo low, slightly anterior. Surface finely concentrically striate, sculpture stronger anteriorly and towards ventral margin. Hinge teeth chevron-shaped, about 15 anterior and 13 posterior, separated by a triangular pit. Length 10, height 5.5, thickness of valve 2 mm.

Type Locality.—Glenelg River at "Roscoe's," Parish of Killara, Western Victoria Werrikooian (Uppermost Pliocene).

Type Material.—Holotype (Pl XX., fig. 2), left valve, coll. and pres. F. A. Singleton, Melb. Univ. Geol. Dept., Reg. No. 1673.

This nearly smooth species distantly recalls the Kalimnan (Lower Pliocene) *Nuculana woodsii* (Tate) (1886, p. 133, pl. 9, fig. 8), which is more inflated, elongate and rostrate.

Dennant and Kitson (1903, p. 146) have recorded from "Limestone Creek," which refers to the same general locality, a worn juvenile of this species as *Leda inconspicua* Adams.

Family LIMOPSIDAE.

Genus **Limopsis** Sassi, 1827.

(*Vide* "Studies," Part I., p. 296, 1932.)

LIMOPSIS WERRIKOOENSIS, sp. nov.

(Pl. XX, figs. 3*a*, *b*.)

Holotype.—Shell ovate, subequilateral, narrowed at hinge, weakly convex; umbo minute, prominent, surface with about 40 narrow radiating ribs, interspaces occupied by fine concentric growth lines, weaker than the radial ornament. Hinge-line narrow, arcuate, bearing 9 anterior and 13 posterior hinge-teeth, slightly curved; ligament pit large, broadly triangular. Interior finely radially striate, inner margin smooth, planate. Length 18, height 18, thickness of valve 4 mm.

Type Locality.—"Limestone Creek" — Glenelg River, Western Victoria Werrikooian (Uppermost Pliocene).

Type Material.—Holotype (Pl. XX., fig. 3*a*, *b*), left valve, ex Dennant Coll., National Museum, Melbourne, Reg. No. 14090.

This differs from its living relative, *L. tenisoni* T. Woods, under which name Dennant and Kitson recorded it, in its less oblique outline and more sloping shoulders on either side of a more acute umbo.

Family GLYCYMERIDAE.

Genus **Glycymeris** Da Costa, 1778.

(*Vide* "Studies," Part I., p. 294, 1932.)

Subgenus **Veletuceta** Iredale, 1931.

Veletuceta Iredale, Rec. Aust. Mus., xviii. (4), pp. 203, 231, 1931.
Type (by original designation): *Glycymeris flammeus* Reeve. Recent, S.E. Australia.

GLYCYMERIS (VELETUCETA) PSEUDAUSTRALIS, sp. nov.

(Pl. XX., figs. 4, 5.)

Holotype.—Right valve of an ephebic example. Subcircular, nearly equilateral, depressed convex; umbo minute, prominent, opisthogyrate. Surface almost smooth, faintly marked by numerous fine radii, about 8 in 5 mm. at the centre of the disc, becoming obsolete posteriorly, and by extremely fine striae; the whole crossed by fine concentric lines and numerous but indistinct growth stages. Hinge-line arcuate; hinge-teeth slender, 10 anterior and 9 posterior, the latter slightly uncinate; ligamental area high, with 5 oblique striae in a space of 2 mm.; inner ventral margin strongly crenate. Length 34, height 31, thickness of valve 9 mm.

Paratype.—A larger right valve which in the gerontic stage is higher than long and somewhat truncate post-dorsally. The surface bears about 40 flat ribs, becoming obsolete anteriorly and posteriorly, with linear interspaces. Length 44, height 45, thickness of valve 13 mm.

Type Locality.—Glenelg River at "Roscoe's," Parish of Killara, Western Victoria. Paratype from Caldwell's Cliff, Glenelg River, Parish of Werrikoo, Western Victoria. Werrikooian (Uppermost Pliocene).

Type Material.—Holotype (Pl. XX., fig. 4), Melb. Univ. Geol. Dept. Reg. No. 1674 and paratype (Pl. XX., fig. 5), Melb Univ. Geol. Dept., Reg. No. 1675, both coll. and pres. F. A. Singleton.

This species recalls the Recent *G. flammea* Reeve = *G. australis* (Q. and G.), which is stouter and more transversely ovate. Its minute but prominent umbo and smoother more depressed shell distinguish it from the Tertiary *G. cainozoica* (T. Woods) and *G. halli* Pritchard.

The imperfect holotype of *G. australis* var. *gigantea* Chapman from the supposed Werrikooian of Kangaroo I., S.A., figured by Chapman and Singleton (1925, p. 47, pl. 3, fig. 32) is not, in my opinion, a glycymerid, but is a lucinid, closely comparable with *Lucina philippinarum* Hanley.

Family OSTREIDAE.

Genus **Ostrea** Linné, 1758.

Ostrea Linné, Syst. Nat., ed. 10, p. 696, 1758.

Type (by subsequent designation, Children, Quart. Journ. Sci., Lit., Arts, xv., p. 44, 1823): *Ostrea edulis* Linné. Recent, Europe.

OSTREA SINUATA GLENELGENSIS, subsp. nov.

(Pl. XX., fig. 6.)

Holotype.—Shell broadly oblong, moderately large, solid, somewhat produced anteriorly to umbo. Lower valve moderately convex, with irregular concentric lamellae and obsolescent radial ribs; upper valve flattened, concentrically lamellate. Muscle scar large, ovate, excavated above, slightly posterior, weakly impressed. Length 93, height 100, thickness of paired valves 35 mm.

Type Locality.—Glenelg River above Limestone Creek, Allot. 16A, Parish of Werrikoo, Western Victoria. Werrikooian (Uppermost Pliocene).

Type Material.—Syntypes (paired valves), coll. and pres. F. A. Singleton, Melb. Univ. Geol. Dept., Reg. Nos. 1676 (left valve, Pl. XX., fig. 6), and 1677 (right valve).

Tate (1886, p. 110) has recorded this fossil as *O. angasi* Sow. (= *sinuata* Lam.) from Limestone Creek and Ascot Heath, and Dennant and Kitson (1903, p. 145) so list it. In the Glenelg Cliffs at Caldwell's Cliff, Ascot Heath and Dartmoor, it forms oyster beds which, from the presence of *Pecten* (*Notovola*) *meridionalis* (Tate), I have recently placed on a slightly higher horizon, probably Lower Pleistocene (1941, pp. 47, 48).

In so variable a genus, it is with some hesitation that the fossils are separated from the common mud oyster of S.E. Australia, to which they are evidently ancestral, but they differ in the greater width at the hinge, the dorsal margin being straight or obtusely angled at the umbo, and the radial ribbing practically obsolete. Victorian *O sinuata*, s. str., is usually more shouldered at the umbo and the radial ribbing of the lower valve is well developed.

A more distant relative is the Lower Pliocene *O. arenicola* Tate, which bears fewer but stronger costae.

Family PECTINIDAE.

Genus **Notochlamys** Cotton, 1930

Notochlamys Cotton, Rec S Aust. Mus., iv (2), p. 233, 1930.

Type (by original designation) · *Chlamys anguineus* Finlay = *Pecten undulatus* Sowerby. Recent, Southern Australia

NOTOCHLAMYS ANTECEDENS, nom. nov.

Pecten praecursor Chapman, 1912, p. 36, pl. 5, figs. 1-3 Not *Pecten (Amusium) precursor* Dall, Trans. Wagner Free Inst. Sci., iii. (4), p. 755, 1898.

Dall's and Chapman's specific names are homonyms, since they are pronounced identically and the difference in spelling is insufficient, according to the International Rules of Zoological Nomenclature, to validate the later name, for which a substitute is therefore offered

Type Locality.—Spring Creek, Torquay, Victoria. Janjukian (Lower Miocene) Paratypes from Waurn Ponds (Janjukian) and Curlewis (Balcombian: by Chapman called Barwonian), both near Geelong, Victoria.

Type Material.—Holotype, left valve, ex Dennant Coll., Nat Mus., Melb., Reg. No. 12590 Paratypes, ex Coll. Geol. Surv Victoria, Nat. Mus Reg. Nos. 12591 (Waurn Ponds) and 12592 (Curlewis).

Family MYTILIDAE

Genus **Aulacomya** Mörch, 1853.

Mytilus (Aulacomya) Mörch, Cat Conch Yoldi, ii, p. 53, 1853.

Type (by subsequent designation, Jhering, Proc. Malac. Soc Lond., iv. (2), p. 87, 1900): *Mytilus magellanicus* Lamarck (as of Chemnitz). Recent, South America

AULACOMYA SUBEROSA, sp. nov.

(Pl. XX, fig. 7.)

"*Mytilus magellanicus* Lamarck." Dennant, 1887, p. 236. Dennant and Kitson, 1903, p. 146. Not *Mytilus magellanicus* Chemnitz, Conch. Cab, viii, p 162, pl. 83, figs. 742-3. Lamarck, Anim. s Vert., vi, p. 119, 1819.

"*Mytilus menkeanus* Philippi" Dennant, 1887, p. 236. Not *Mytilus menkeanus* Philippi. Zeit. f. Malak., iv., p. 118, 1847 (= *M. erosus* Lamarck, 1819).

Holotype.—Shell elongately subtrigonal; inflated anteriorly, compressed posteriorly; umbo acute, slightly curved; dorsal margin straight, passing evenly into the regularly rounded posterior margin; anterior margin very long, straight. Area anterior to the elevated umbonal ridge very steep, with fine radial riblets, about 1½ per mm. Sculpture of coarse, wavy radial riblets, narrower than the interspaces, increasing by occasional bifurcation or intercalation, about 20 at the posterior margin, where they are about 2 mm. apart; on the precipitous area anterior to the strong umbonal ridge they are finer and average 1½ per mm.: growth stages prominent. Margins very worn, but apparently smooth, with ligamental groove dorsally. Greatest length 61, greatest width at right angles 20, thickness 9 mm.

Type Locality.—"Limestone Creek" — Glenelg River, Western Victoria Werrikooian (Uppermost Pliocene).

Type Material.—Holotype (Pl. XX., fig. 7), ex Dennant Coll., Nat. Mus., Melb, Reg. No. 14091.

The straight (rarely concave) anterior margin, acute beaks and absence of a post-dorsal bulge at once distinguish it from *A. erosa* Lk, now living in this region. There is a closer resemblance to the Neozelanic *A. maoriana* (Iredale), in which the beaks are more curved and the ribbing slightly finer. Kerguelen shells labelled as *Mytilus magellanicus* differ again in outline and have coarser ribbing than either of the preceding.

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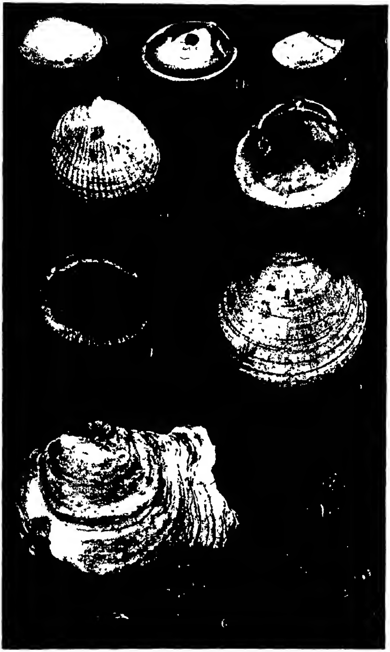
Explanation of Plate.

PLATE XX.

FIG. 1A, B—*Nucula (Ennucula) gricei*, sp. nov. Holotype, × 2.
FIG 2—*Nuculana (Scaeoleda) hillare*, sp. nov. Holotype, × 2.
FIG 3A B—*Limopsis werrikooensis*, sp nov. Holotype, × 2.
FIG 4—*Glycymeris (Veletuceta) pseudaustralis*, sp. nov. Holotype, nat. size.
FIG 5—*Glycymeris (Veletuceta) pseudaustralis*, sp. nov. Paratype, nat. size.
FIG 6—*Ostrea sinuata glenelgensis*, subsp nov. Syntype, lower valve, × ⅔.
FIG 7—*Aulacoyma suberosa*, sp nov Holotype, nat size.



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Australian Tertiary Mollusca.

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The names of new genera and species are printed in italics

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[PROC. ROY. SOC. VICTORIA, 54 (N.S.), PT. I., 1942.]

ART. I.—*Notes on Two Australian Fungi of the "Sooty Mould" Group.*

By EILEEN E FISHER, Ph.D. (Cantab.), M.Sc. (Melb.).

Botany School, University of Melbourne.

[Read 3rd April, 1941; issued separately 15th April, 1942.]

LIMACINIA PHLOIOPHILIA n. sp.

Mycelio in cortice crescente; interdum per summam stirpem arboris aequaliter patente, sed in ingenti magnitudine massas, pulvinis similes, saepe aggregato. Hyphis septatis, cellulis proxime aequis diametris. Maturis hyphis, septis plane constrictis, Saccardi pigmento fusco (*umber*) (*Ridgway*) *plerumque diametro* 44·5 μ. *Juvenibus hyphis, in duas partes divisis, ad apicem attenuatis* (*plerumque diametro* 9·4 μ), *olivaceo-fulvo* (*Ridgway*). *Conidiis in hyphis terminantibus, Saccardi pigmento fusco* (*umber*) *fusiformibus laterculis in muro similibus formatis septatis,* 4–5 *transversis septis,* 32–38 *plerumque longis* 34·8 μ × 11–13·5 *plerumque latis* 13·2 μ *Similes hyphis appendices conidia interdum ferentes ex base ascocarporum oriuntur. Ascocarpis globosis, sessilibus, ora ferentibus,* 183-332 *plerumque* 249 μ *diametro Paraphysibus; ascis tenuibus muris, evanescentibus, octosporis Ascosporibus Saccardi pigmento fusco* (*umber*), *fusiformibus paulum curvatis, phragmoseptatis* (14–17 *septis*) 103–148 *plerumque* 116 μ *longis* × 8–14 *plerumque* 10 μ *latis* Loca: *Stirpibus* Kunzeae peduncularis *F.v.M. Warburtonensi Victoriae carptis, et* Leptospermo lanigero *specie* montana *Smithi, in Valle Cradle Tasmaniae carpto*

This "sooty mould" was found first at Warburton, 50 miles E.N.E. of Melbourne (altitude 523 feet) It was growing on *Kunzea peduncularis* F.v M., which was infected with the woolly coccid, *Pulvinaria tecta* var *alba* Maskell. More recently this fungus has been collected at Cradle Valley (altitude 3,100 feet) in Northern Tasmania, occurring on *Leptospermum lanigerum* var. *montanum* Smith. Also in this locality, a mould very similar to that produced by *Limacinia phloiophilia* was found on *Melaleuca squamea* Lab., another member of the family *Myrtaceae.* However, as this specimen exhibited vegetative structure only, it could not be identified with certainty.

Limacinia phloiophilia appears to be restricted to the stems of plants provided with abundant papery bark. The mycelium, which inhabits the superficial layers of bark only, may extend evenly over the surface of the stem, but it is frequently aggregated to form cushion-like masses of considerable size. The specimen

photographed (Plate I fig 5) measured 3 inches in diameter When as during the winter vegetative growth is prolific the surface of these mycelial masses is sepia (Ridgway) but later it darkens to black

The young hyphæ are tawny olive (Ridgway) dichotomously branched and taper towards the apex where the average diameter is 9 4 μ in the adult condition they are darker (Saccardo s umber (Ridgway)) and measure 44 5 μ in diameter (Plate I fig 1) The cells are approximately isodiametric and the mature hyphæ are conspicuously constricted at the septa

The conidia arise terminally on the hyphæ and are of the same colour they are fusiform muriform septate with 4 5 transverse walls but the longitudinal septa are sometimes lacking (Plate I fig 3) The conidial dimensions are length 32 38 μ aver 34 8 μ width 11 13 5 μ aver 13 2 μ

The mature ascocarps are visible to the naked eye as small black spots on the surface of the stromatic mycelium They are spherical and sessile towards the apex the wall is thin forming a fairly well defined ostiole and hyphal appendages which sometimes bear conidia arise from the base (Plate I fig 4) Paraphyses are present and the asci which are thin walled and evanescent contain 8 spores When mature these ascospores are coloured Saccardo s umber they are phragmoseptate (14–17 septa) and fusiform but slightly curved They measure 103 148 μ aver 116 μ in length and 8 14 μ aver 10 μ in width (Plate I fig 2) The ascocarps are of variable size 183 332 μ aver 249 μ in diameter

HYSTEROSTOMELLA FILICINA (B & Br) v H

In the fern gullies near Melbourne *Hysterostomella filicina* is frequently found as a parasite on the tree fern *Dicksonia antarctica* Labill The specimens described in this paper were collected at Marysville 63 miles N E of Melbourne but others have been found in the gullies to the east at Kallista and Gembrook

On the under surface of infected fronds *H filicina* forms black patches or stromata which on cursory examination resemble the tar spot fungus *Rhytisma acerinum* It is possible however to differentiate these two species by means of sections and for this purpose material was fixed in the fluid known as 2 B D (La Cour 1931) Microtome sections of about 8 μ were cut and stained with Heidenhain s iron alum haematoxylin followed by a counter stain of eosin The stromata of *H filicina* may be readily distinguished by the fact that this species does not penetrate the cells of the leaf The hyphæ are intercellular they accumulate in the stomatal air cavities forming masses of hyaline

plectenchyma strands of which emerge between the guard cells and attach a superficial stroma of olive coloured hyphae (Ridgway) to the surface of the leaf. Several such organs of attachment occur beneath each stroma (Plate I, fig. 6). These plates of hyphae are more or less circular, approximately 2.5 mms. in diameter, and each comprises several irregularly arranged loculi which contain asci but no paraphyses. The mature ascospores are yellowish citrine (Ridgway), bi-cellular and they measure 8–11 $\mu \times 2.7\ \mu$.

This fungus has not been previously recorded on *Dicksonia antarctica*; furthermore, its confused taxonomy required investigation.

The type material was collected on *Alsophila gigantea* and it was described by Berkeley and Broome (1875) under the name of *Rhytisma filicinum* B. and Br.

The inaccuracy of this nomenclature was realized by Saccardo (1889) who transferred the species to the genus *Marchalia* Sacc.

Later, von Hohnel (1909) examined the type material and referred it to the genus *Hysterostomella* Speg.

More recently, however, to accommodate this species Theissen and Sydow (1915) have created a new genus *Monorhizina*, because in their opinion each ascostroma is fixed to the leaf by a single central attachment, while *Hysterostomella* is characterized by several points of insertion.

Through the courtesy of the Director of the Kew Herbarium I have examined a fragment of the type material of *Rhytisma filicinum*. Although this specimen was insufficient to prove the multiple attachment of the ascostromata, it served to confirm the identity of the species occurring on *Dicksonia antarctica*. The latter, as already indicated, illustrates clearly that each ascostroma is attached to the leaf at more than one point (Plate I, fig. 6).

Furthermore this feature was described by von Hohnel (1909), when he examined the type material of *Rhytisma filicinum* and upon this basis he differentiated it from the closely related *Hysterostomella rhytismoides* in which a central hypodermal stroma was observed.

Conflicting evidence was supplied by Theissen and Sydow (1915). Apparently they did not examine the type material, however, and the new genus which they formed to accommodate *Rhytisma filicinum* is not accepted by me. The easily detachable character of the ascostroma they attributed to a solitary organ of attachment, but this is due rather to the absence of any hypodermal stroma. The hyphæ do not penetrate the cells of the leaf but merely accumulate in the small air cavities beneath the stomata.

I suggest therefore that von Höhnel correctly referred *Rhytisma filicinum* to the genus *Hysterostomella*, and the fungus parasitizing *Dicksonia antarctica* is identified as *Hysterostomella filicina* (B. and Br.) v. H.

Specimens of both species described in this paper have been sent to The National Herbarium, Kew, England

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Explanation of Plate.

Plate I.

1. Young hyphæ of *Limacinia philoophilia*. × 85
2. Ruptured ascocarp of *Limacinia philoophilia*. × 125.
   a = young ascus, b = mature ascus, c = paraphysis.
3. Conidial bearing hyphæ of *Limacinia philoophilia* × 175
4. Ascocarps of *Limacinia philoophilia* × 90
   a = hyphal appendage bearing a conidium
5. *Limacinia philoophilia*. Natural size
6. T S. Frond of *Dicksonia antarctica* infected with *Hysterostomella filicina* (B & Br) v.H. × 300
   a = two loculi in a superficial ascostroma; b = mass of plectenchyma filling a stomatal air cavity, note hyphæ emerging between the guard cells.

[PROC. ROY. SOC. VICTORIA, 54 (N.S.), PT. I., 1942.]

ART. II.—*The Pakenham Meteorite.*

By A. B. EDWARDS, Ph.D., D.I.C., and G. BAKER, M.Sc.

[Read 3rd April, 1941; issued separately 15th April, 1942.]

Introduction.

The Pakenham meteorite was found during the widening of the Princes Highway in 1928, at a point 3 miles west of Pakenham township, in the Parish of Berwick, County of Mornington. It was discovered in soil at a depth of 3 feet, and was collected by an officer of the Country Roads Board. A small fragment, weighing only a few ounces, and now lost, was knocked off one corner and sent to the Mines Department of Victoria for identification. Subsequently the meteorite was obtained for the Mines Department by Mr. D. J. Mahony, then Government Petrologist, and lodged in the Geological Survey Museum in February, 1929. The meteorite was coated with limonite scale when found, and weighed 89 lb. It continued to rust and scale in the Museum, and in December, 1936, this had reduced its weight to 71 lb., a loss of 18 lb. in nearly eight years.

This meteorite closely resembles both in chemical and mineralogical composition the other masses of meteoritic iron found in this part of Victoria, namely, the Cranbourne, Beaconsfield, and Langwarrin meteorites. Walcott (8) has shown that the localities from which these several meteorites were obtained lie more or less on a straight line, suggesting that they were all derived from the breaking up of a single large iron meteorite during flight. The location of the Pakenham meteorite also conforms to this line, and it was probably derived from the same source.

Hodge-Smith (3) records the occurrence of an undescribed iron meteorite from what is apparently the same locality as that of the Pakenham meteorite, under the name of "Cranbourne No. 6". He records the weight of this "Cranbourne No. 6" as 9·0 kg. (20 lb.), and states that it was secured by Mr. D. J. Mahony in

1928 and lodged in the National Museum Melbourne. It would appear that the Pakenham meteorite and the "Cranbourne No. 6" might be one and the same but it seems that Hodge Smith's record is incorrect. There is no meteorite corresponding to the "Cranbourne No. 6" in the collection of the National Museum nor was a piece of iron weighing 20 lb. removed from the Pakenham meteorite and this is borne out by the appearance of the meteorite. While the meteorite under discussion may well be the "Cranbourne No. 6" of Hodge Smith we propose to avoid confusion by naming it after the locality in which it was found.

Description of the Meteorite

When submitted to us for examination the Pakenham meteorite was roughly ellipsoidal in shape measuring 12 in. $\times$ 7.5 in. $\times$ 6.5 in. and was coated with limonite scale. As in most of the Cranbourne meteorites any original surface features have been completely destroyed by scaling and rusting. Its weight, as received was 65 lb. (December 1940) representing a further loss in weight of 6 lb. between December 1936 and December, 1940.

Nodules

With the meteorite came several nodules which had been recovered from time to time from the scale falling from it during its sojourn in the Geological Survey Museum and similar nodules were discovered when de-scaling the iron to slice it. These nodules resemble those found in the other Cranbourne meteorites. They are generally ellipsoidal in shape but one was pear-shaped. They consist of a core of pyrrhotite sometimes enclosed by a zone rich in graphite and surrounded by a narrow rim of iron-nickel phosphides (Fig. 2). A thin band of limonite generally occurs between the phosphide rim and the sulphide core, and veinlets of limonite have invaded the sulphides. The largest nodule found (Fig. 2) measured 40 mm. $\times$ 30 mm. $\times$ 21 mm. and weighed 45 grams. It had a specific gravity of only 3.643, while smaller nodules had specific gravities of the order of 4.5–4.7. The low value of the large nodule is due to the presence of abundant graphite in it.

Preparation of the Specimen for Examination

The meteorite was first de-scaled with a cold chisel and a hammer; about 5 lb. of scale were removed and kept for examination. It was then taken to the Metallurgy School, University of Melbourne and cut with an oxy-acetylene flame by Mr. A. Wilcock. The meteorite and the piece cut from it were cooled first in a stream of compressed air and then in a bath of water. Flat surfaces were obtained by treating both pieces in a shaping machine in which all the fused material was removed, as well as a considerable further thickness to ensure the elimination

of any heat effect on the structure of the iron Tool marks were removed by subsequent grinding with various grades of carborundum, and a final polish was obtained on a buffing machine During the shaping process it was noted that the marginal portion of the iron was harder than the centre A mirror like polish was obtained but rusting developed on the surface within 48 hours The surface was then re polished etched with 2 per cent nitric acid in alcohol to bring out the octahedral structure and treated to preserve it from further rusting No pyrrhotite nodules were encountered either during the cutting or the shaping

After these operations the main mass of the meteorite weighed 56 5 lb This is now in the Geological Survey Museum (No 8150) Several small pieces weighing altogether 4 oz were sawn off the piece that had been removed and polished for mineragraphic examination These and the polished remainder of the slice weighing 1 lb 4 5 oz are lodged in the Melbourne University Geological Museum

Widmanstatten Structure

Etching of the two large polished surfaces with 2 per cent nitric acid in alcohol brought out pronounced Widmanstatten figures (Fig 1) The width of the lamellae of kamacite forming this structure varied from 1 mm to 7 mm and the average of 41 measurements was 3 mm On this basis the Pakenham meteorite may be described as a coarse octahedrite and falls into the group (Og) of Prior s classification (5)

Specific Gravity

The specific gravity of the large slice removed from the end of the meteorite is 7 20 that of the smaller pieces sawn from this 7 032 and that of a selected sample of fresh clean shavings collected during the final shaping treatment 7 927 The value obtained from the shavings is probably the more accurate measurement for the actual iron since the shavings were free from cracks and nodules The lower figures for the larger pieces may be put down to the presence of air films in cracks and possibly the presence of nodules of pyrrhotite

Chemical Analysis

A chemical analysis (Table 1 Column No 1) was made from a sample of 2 5 gm of fresh clean shavings obtained during the final stage of shaping the meteorite

The sample was not wholly representative of the meteorite since it contained neither sulphur nor carbon although both these elements are present in the nodules of the meteorite as pyrrhotite and graphite No determination was made for chlorine but this element was also proved to be present during the mineralogical examination Disregarding these inadequacies however it will be seen that the Pakenham meteorite closely resembles the

Cranbourne No 2 and is not greatly different from the other irons from this district It also indicates that the Pakenham meteorite belongs to the nickel poor coarse octahedrite group

TABLE 1

	1		3	4	
Fe	92 31	91 08	9 84	93 56	9 8
Ni	6 81	8 11	6 38	7 34	1 24
Co	0 54	0 80	0 75	0 48	58
Cu	nil	0 01	0 02	0 02	0 06
P	0 37	0 11	0 19	0 26	0 17
S	nil		) 18	0 04	
C	n d			0 05	
Cl	n d			0 01	
Insoluble	nil	0 17			0 32
Totals	100 03	99 98	9 8	100 76	9 55
Fe Ni	13 5	11 2	14	12 6	14 8
Sp Gr	93	46			

1 Pakenham meteorite anal —A B Edwards
2 Cranbourne N 1 anal —W Flight (2)
3 Cranbourne N 2 anal P G W Bailey and A Hall (8)
4 Beaconsfield anal O Sjostrom (8)
Langwarrin anal P G W Bailey and A G Ha (8)

Mineral Composition

Microscopical examination of polished sections of the nickel iron and of the nodules reveals that the iron is composed chiefly of kamacite (α nickel iron), with minor amounts of taenite (γ nickel iron) and various phosphides The nodules consist of pyrrhotite and graphite the pyrrhotite forming the core enclosed by a narrow rim of iron nickel phosphides with an inner margin of limonite In addition minute parallel strings of a grey white mineral possibly daubreelite were observed in the pyrrhotite The oxidized crust or scale of the meteorite consists chiefly of limonite with residual patches of nickel iron and the phosphides In places trevorite is associated with it and some of the scales are encrusted with small quantities of the chlorides of iron and nickel

Kamacite (α *nickel iron*) is iron white and isotropic strongly magnetic and readily scratched with a steel needle Standard etching reagents behave as follows —HNO_3 produces an immediate etching but without effervescence HCl fumes tarnish and the iron washes and rubs brown but the effect is not consistent KOH and KCN are negative $FeCl_3$ instantly turns the iron brown bringing up grain boundaries and etching grains differentially as well as bringing up a few Neumann lines $HgCl_2$ darkens the surface immediately Of the other etching reagents tried 2 per cent picric acid in alcohol and bromine water both attack the kamacite darkening it and bringing up grain boundaries and crystal structure by differential etching

Taenite (γ *nickel-iron*) is present only as occasional groups of parallel lamellae between plates of kamacite (Plate III figs 5 and 6) and as small triangular areas in the interstices of kamacite grains The taenite occurs in the dark bands that outline the Widmanstatten structure (Plate II fig 1) The appearance of the etched specimen is misleading however in that it gives the impression that the dark bands are broad and uniform Actually the dark bands consist of closely interleaved narrow lamellae of taenite and kamacite (Plate III fig 5)

The taenite is scarcely distinguishable from the kamacite in unetched sections but is readily distinguished after etching with picric acid bromine water or 2 per cent HNO_3 in alcohol all of which darken the kamacite but do not affect the taenite Standard etching reagents behaved as follows —HNO_3, KOH KCN $FeCl_3$, $HgCl$ were all negative HCl fumes tarnished the taenite a deeper brown than they did the kamacite but the results were not consistent The taenite is strongly magnetic isotropic and is readily scratched with a steel needle

Where the taenite forms triangular areas at the junction of several crystals of kamacite it commonly forms a fine grained ex solution intergrowth with the kamacite The kamacite occurs as minute ex solution bodies of lens like form with their long axes parallel to one or other of three directions This structure is closely comparable with that observed in the Tawallah Valley meteoric iron (1) The transformation of γ nickel iron (taenite) into α nickel iron (kamacite) as indicated in this connection is accompanied by a gradual enrichment of the residual γ nickel iron in nickel This has the effect of depressing the temperature of transformation and finally the residual γ nickel iron becomes so enriched in nickel that the temperature of transformation is depressed too low for the change to continue The alloy then becomes stable is a mixture of α nickel iron and γ nickel iron the proportion of the two constituents depending on the composition of the original γ nickel iron Further it was shown that the transformation proceeds by the development of small bodies of α nickel iron in the octahedral directions of the original γ nickel iron and that as the transformation progresses these bodies grow in size by solid diffusion forming oriented lamellæ and forcing residual γ nickel iron to take up its position interleaved between these lamellæ Thus arises the Widmanstatten structure The Tawallah Valley iron was of such a composition that this transformation was unable to progress beyond the stage when small oriented ex solution bodies of α nickel iron had developed in the base of γ nickel iron The nickel content of the Pakenham meteorite on the other hand is such that the transformation went almost to completion and it was only checked when a minute amount of nickel rich γ nickel iron remained The very thin lamellae of this residual γ nickel iron appear homogeneous, but the slightly larger triangular areas reveal the ex solution structure by which the transformation was accomplished

Pyrrhotite has been observed only in the cores of nodules picked out from the weathered parts of the meteorite It has a creamy brown colour is strongly anisotropic and pleochroic and strongly magnetic In some nodules it forms innumerable minute interlocking grains, while in others it occurs as two or three coarse grains In still others patches of coarse grained pyrrhotite interdigitate with patches of finer grain It is readily distinguished from troilite by its etching reactions Thus HNO_3 tarnishes the surface but washes clean whereas with troilite it causes vigorous effervescence and the evolution of H_2S Again HCl fumes tarnish the surface of the pyrrhotite but do not otherwise affect it whereas troilite effervesces vigorously with HCl and is stained brown Of the other reagents KCN $FeCl_3$ and $HgCl_2$ are negative while KOH slowly stains the surface brown and reveals the presence in the pyrrhotite of parallel strings of grey inclusions (Plate III fig 8) Microchemical tests indicate that it is not nickeliferous

The pyrrhotite may form the whole of the nodule core when it is enclosed by a thin rim of iron nickel phosphides from which it is separated by a narrow zone of limonite or it may occur as an irregular shaped core surrounded by a zone of pyrrhotite intergrown with graphite (Plate II fig 2) The proportion of graphite tends to be greater near the outer edge of the nodule where it gives place to a zone of clear pyrrhotite enclosed in turn by a narrow rim of phosphides and limonite

Graphite was also found as occasional flakes in part of the limonitic coating of the meteorite In polished sections it is a brownish grey colour showing distinct anisotropism and pleochroism It is soft brittle inert to all etching reagents and marks paper

(?) *Daubreelite* —The blebs of grey mineral occurring as small parallel strings in the pyrrhotite (Plate III fig 6) are thought to be the rare chromium sulphide daubreelite This mineral has been recorded from the Cranbourne No 1 meteorite by Flight (2) and Smith (6) where it formed zones about the troilite in troilite nodules and from the Langwarrin meteorite by Walcott (8) who regarded extremely fine veins traversing the thick vein of troilite which was exposed in the polished face of this meteorite as daubreelite because an analysis of the troilite revealed a trace of chromium

The mineral in the Pakenham meteorite is isotropic and inert to all etching reagents and is harder than the enclosing pyrrhotite The individual blebs forming the strings are too small however to test microchemically The orientation of the strings is parallel to a crystallographic direction of the pyrrhotite and the direction of the strings varies from grain to grain of pyrrhotite

Iron nickel Phosphides—Four varieties of iron nickel phosphide have been observed in the meteorite Of these two occur as rims around pyrrhotite nodules and always associated together

The other two occur in the nickel-iron, and do not appear in the nodules. Of the two forming the rims about the nodules, one is identified as schreibersite, while the other corresponds to the brassy coloured phosphide recorded from the Cranbourne No. 1 meteorite Of the two in the iron, one has been identified as rhabdite, while the other is probably a variety of schreibersite, of somewhat different composition to that in the nodule rims It is referred to here as "schreibersite B". All four show distinctive features in their appearance, and particularly in their behaviour to standard etching reagents, as set out in Table 2.

TABLE 2

ETCHING BEHAVIOUR OF PHOSPHIDES

—	HNO_3	HCl	KCN	$FeCl_3$	$HgCl_2$	KOH
Rhabdite						
Schreibersite	+	·		·		+
Schreibersite B		+	·			·
Yellow phosphide	·				+	·

Rhabdite.—This occurs as small rhombs and prisms scattered throughout the massive kamacite (Plate III., figs. 2, 3) in a manner and form identical with the descriptions of rhabdite cited by Walcott (8) and figured by Johnston and Ellsworth (4). It is much harder than the enclosing iron and cannot be scratched with a steel needle It is brittle and brown by contrast with the iron, strongly magnetic, and distinctly anisotropic Tests on a small amount of powder composed of such rhombs, and obtained as the insoluble residue from 50 grams of iron which had been dissolved in 1:1 HNO_3, gave tests for iron, nickel, and phosphorus.

Schreibersite.—This is a tin-white, brittle, hard mineral which cannot be scratched with a steel needle, occurring as the outer rims to the pyrrhotite nodules (Plate III., fig 7). It is difficult to polish owing to its brittle nature, and is distinctly anisotropic, and strongly magnetic Tests on fragments gave positive tests for iron, nickel, and phosphorus. When etched with HNO_3 it effervesces very slowly, the bubbles rising from the numerous cracks that traverse the surface On treatment with KOH it tends to develop a brown stain, which washes brown, and rubs pale brown. This action is a very slow one, and may take place only after several minutes. Sometimes it takes place with a single application of KOH, sometimes only after two or three applications to the same spot.

Yellow Phosphide.—Associated with the schreibersite, but subordinate to it, is a creamy yellow material (Plate III., fig. 7).

This is softer than the schreibersite being readily scratched with a needle and lacks the brittleness of the schreibersite Moreover it does not appear to be magnetic and is isotropic Powder excavated from a large crystal gave positive tests for iron nickel and phosphorus the nickel test being particularly strong The mineral is negative to all the etching reagents but $HgCl_2$ With $HgCl_2$ it is slowly stained brown to purplish brown The stain washes the same colour and is difficult to rub off when it leaves a slightly roughened surface

Schreibersite B—The fourth phosphide occurs as occasional large irregular areas whose shapes are partially controlled by the octahedral structure of the iron (Plate II fig 1) but generally as vein like areas in the interstices of the α nickel iron crystals (kamacite crystals) and is extremely difficult to polish on account of its brittleness (Plate III fig 6) It is weakly anisotropic, and in hardness brittleness magnetic property and general appearance it resembles schreibersite In colour however it is almost identical with the rhabdite crystals in the adjacent iron crystals while in etching properties it is distinct from both Unlike schreibersite it is negative to both HNO_3 and KOH but with HCl it effervesces slowly the bubbles rising from the numerous cracks and this latter behaviour distinguishes it from the rhabdite which is negative to HCl Tests on minute fragments broken from a vein with a micro drill gave tests for iron nickel and phosphorus

Walcott (8) described material of similar occurrence in the related Cranbourne No 2 meteorite as schreibersite but with the remark that it differs seriously in composition fr m that usually ascribed to schreibersite

The chemical analyses f the vari us phosphides found in the related Cranbourne and Beaconsfield meteorites (8) are summarized in Table 3 and shew that the chief variant is the Ni/Fe ratio the proportion of Ni ranging from 42 5 to 14 5 per cent

TABLE 3

ANALYSES OF PHOSPHIDES

Mineral	Ni	Fe	P	Meteorite
Rhabdite	42 5	41 5	15	Beaconsfield
	38	49	13	Cranbourne No 1
Schreibersite	29	56	13	Cranbourne No 1
	22	70	7	Cranbourne No 2
	22		8 5	Cranbourne No 2
	18	66	14	Beaconsfield
	20	67 5	13	Cranbourne No 1
Yellow phosphide	14 5	69 5	16	Cranbourne No 1

This probably accounts for most of the variation in the phosphides At the same time, it seems probable that there are two series of phosphides, one of which contains about only half as much phosphorus as is found in the more common varieties It seems possible that this may be the fourth variety—schreibersite B—described above

Oxidation Products—Many of the fragments of scale removed from the meteorite consist of numerous unreplaced remnants of nickel-iron up to 3 mm in diameter cemented together by ramifying limonite Sometimes even larger plates of iron were preserved Such fragments generally have a hackly fracture and, when polished simulate an iron-limonite breccia Other pieces of the scale are sheet-like or lens-shaped, and consist essentially of limonite showing well-shaped colloform banding The limonite is studded with minute prisms and rhombs of rhabdite, much in the manner of the original iron No trace of the schreibersite B veins was observed, and in view of the ready attack of HCl on this mineral it is thought that the presence of lawrencite in the meteorite could be held accountable for this

Trevorite—Intercalated with the limonite bands are bands of a pinkish brown mineral which appears to have formed along either side of the open cracks It is an isotropic mineral which is inert to all etching reagents but hot HCl, and is hard but can be dug out with a micro-drill The powder so obtained is distinctly magnetic and yields positive microchemical tests for both iron and nickel It is regarded therefore as trevorite, and resembles the trevorite found by Stillwell (7) in the Caroline meteorite

Chlorides—In places the scale is coated with minute pustules of yellow and green substances The yellow material sometimes appears first as liquid drops, darkens on exposure, and turns dark brown in a few days Some of it was quite soft at first, but became sticky after exposure for a period Microchemical tests showed that this material consists of ferric chloride, indicating that it is *lawrencite*

The green encrustations have the colour of a nickel salt, and microchemical tests proved the presence in them of nickel and chlorine with a trace of iron The iron was probably derived from attached limonite so that the encrustations probably consist of nickel chloride

Acknowledgments.

In conclusion, we wish to thank Mr W Baragwanath, Director of the Geological Survey of Victoria, for permission to examine the meteorite Much helpful information concerning its occurrence and history was received from Mr D J Mahony, Director of the National Museum and the late Mr W Abrahams, Curator of the Geological Survey Museum

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Explanation of Plates.

Plate II

Fig 1 —End on view of the Pakenham meteorite showing Widmanstatten structure on the polished surface which has been etched with 2 per cent HNO_3 in alcohol The oblique lighting makes the taenite appear as dark lamellae Actually these dark bands are composite, consisting of thin parallel lamellae of taenite interleaved with kamacite as shown in Fig 5 An unusually large area of schreibersite B occurs near the right hand edge of the polished surface Its shape is largely controlled by the octahedral structure of the iron (Magnification one half) (J S Mann photo)

Fig 2 —Polished section through the centre of a large pyrrhotite nodule The irregular dark core consists of fine grained pyrrhotite the light zone around this consists of graphite and *pyrrhotite* intergrown with a *narrow* dark marginal zone of clean pyrrhotite Enclosing this is a narrow rim of limonite and iron nickel phosphides The phosphides appear white (J S Mann photo)

Plate III

Fig 3 —Shows the typical occurrence of rhabdite as small rhombs and prisms in the kamacite after etching with *2* per cent picric acid in alcohol (× 150)

Fig 4 —Typical rhombs of rhabdite in kamacite etched as above (× 660)

Fig 5 —A typical dark band of the Widmanstatten structure shown in Fig 1 revealing its composite character Thin parallel lamellae of taenite, with characteristic saw tooth margins occur interleaved with bands of kamacite The small clear area interrupting one taenite lamella (top right) consists of phosphide Etched as above (× 1 0)

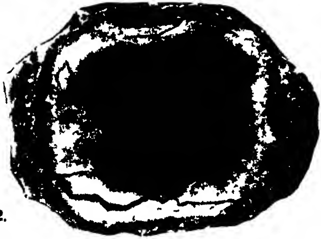
Fig 6 —Parallel lamellae of taenite in kamacite On the left is a typical vein like occurrence of schreibersite B along the grain boundary between kamacite grains Its brittleness makes it difficult to polish and gives it a characteristically fractured and pitted surface Etched as above (× 100)

Fig 7 —Portion of an iron nickel phosphide rim enclosing a pyrrhotite nodule The white areas are schreibersite The gray area (with scratches) separating the schreibersite areas consist of the softer creamy yellow phosphide (× 80)

Fig 8 —Minute lenticular bodies of (?) daubreelite forming parallel strings in a single pyrrhotite grain Etched with saturated *KOH* The same nodule as in Fig 7 (× 400)

1.

× ½.



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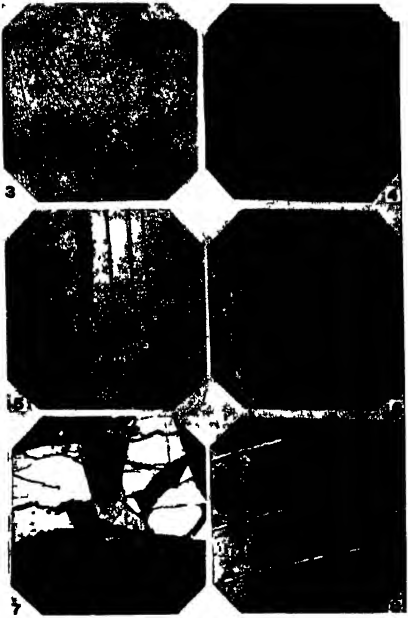
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[Proc Roy Soc Victoria 54 (N S) Pt I 1942]

Art III—*On the Thickness and Age of the Type Yeringian Strata Lilydale Victoria*

By Edmund D Gill B A B D

[Read 12th June 1941 issued separately 15th April 1942]

Contents.

The Yeringian Series

The Yeringian Series was named by Professor J W Gregory (1903 p 172) in these words The second series we may call the Yeringian after Yering north of Lilydale where the beds have yielded a small brachiopod fauna These beds are best shown at Lilydale but the name Yeringian is preferable as based on a native Australian place name This Yeringian series includes the most important Silurian limestones including those of Lilydale Loyola the Thomson River Cape Liptrap and also the beds of Seville and various localities in the basin of the Woori Yallock Gregory referred the beds at Reefton McMahons Creek Alexandra and Matlock to the Melbournian Series Junner (1920) referred these beds which he called *Tanenka* Beds to the Yeringian Chapman (1913 1924) instituted the Tanjilian Series to receive these same beds Skeats (1928) showed that Chapman s sequence was incorrect and abandoned the name Tanjilian Chapman and Thomas (1935) accepted Skeats correction of the sequence but defined the Silurian sequence of Victoria as Keilorian Melbournian and Yeringian omitting the Tanjilian They provide lists of fossils for the above three series but none for the Tanjilian They do not include the characteristically Tanjilian fossils in either the Melbournian or the Yeringian lists Thomas (1939) mapped the former Tanjilian beds with the Yeringian Series The present writer (Gill 1941) gave further grounds for rejecting the name Tanjilian and in re defining the Series proposed the name Jordanian The Yeringian Series in the view of the present writer is the same in extent as originally given by Gregory The latter thought there might be some Yeringian beds in the area east of Warburton (1903 p 171 and section Plate XXV fig 5) and this has proved to be so (Gill 1941)

The fossils of the Yeringian Series have been described by McCoy Etheridge Cresswell Chapman Jones Ripper Hill and others Recently the author (Gill 1940*b*) contributed a paper extending our knowledge of the geographical extent and palaeontological content of the type Yeringian strata A further paper (Gill 1941) referred to the discovery of a fossiliferous conglomerate which is the southerly extension of a bed mapped by Jutson (1911) This conglomerate is considered to be possibly the base of the type Yeringian Series The fauna is not well preserved but the following forms have been noted

COELENTERATA Specimens of corals were sent to Dr Dorothy Hill who has kindly made the following identifications—

Favosites sp reminiscent of *F nitidus* Chapman

Heliolites sp

Heliolitids possibly *Heliolites* It could be *H daintreei* but there is no possibility of proof

Possibly *Prismatophyllum* but with more septa than *P stevensi* and longer septa than *P chalkii*

A large simple rugose coral which could be *Mictophyllum*

BRYOZOA

Reptaria sp

Other undetermined Bryozoa common

BRACHIOPODA

Camarotoechia sp

Chonetes bipartita Chapman

Chonetes sp nov (also at Lilydale)

Cyrtina sp

cf *Dalmanella elegantula* (Dalman)

Nucleospira cf *marginata* Maurer

Plagiorhyncha decemplicata (Sowerby)

Spirifer of *lilydalensis* Chapman type

CRINOIDEA

Abundant stem joints

Favosites nitidus is known at Cooper s Creek in the Walhalla District (Chapman 1914*c* Jones 1937) in beds of similar age to the Warrandyte South Quarry deposits The writer has recently found this fossil (kindly determined by Dr Hill) at Cave Hill Lilydale However because of the imperfect preservation of the corals at Warrandyte they are of little help in correlation

The Bryozoan *Reptaria* has already been recorded from basal Yeringian beds near Yankee Jim Creek Upper Yarra District (Gill, 1941) where it is associated with *Anoplia* The author

has found this genus in a heavy conglomerate on the Yea Alexandra road three quarters of a mile west of Molesworth in a large cutting on the south side of the road Also in the Merriang syncline (Yeringian) at Jutson s locality viii (1908 Plate iii)

The brachiopods in the Warrandyte South Quarry conglomerate are of Yeringian aspect Thus although the fauna of the Warrandyte South Quarry (by which name it is proposed that the locality be known) is poorly preserved the cumulative evidence of the fossils suggests a Yeringian age The conglomerate and grit are quarried for road maintenance purposes an excavation 6½ chains long and 24 feet wide having been made The quarry is long and narrow because the excavation has followed the conglomerate along the line of strike The section at the southern end of the quarry shows 5 feet of conglomerate then 5 feet of quartzitic grit followed by another band of conglomerate 14 feet wide The pebbles of the conglomerate which are of all sizes up to 11 inches in diameter are composed principally of quartz and quartzite Some are of sandstone The conglomerate is stratified the beds dipping easterly at 70 degrees and striking north 15 degrees east Jutson (1911 Plate xcii) has mapped this conglomerate in its northerly extension As Jutson has shown the Warrandyte Anticline is surmounted at Warrandyte by a series of small folds The conglomerate is repeated on these various folds The present writer has found the conglomerate further south on the north side (half way down the hill) of the road which proceeds west across Anderson s Creek from the north end of Park Orchards (Military Map reference Ringwood 236 421) Selwyn (1852) mapped a conglomerate still further south on the Mullum Mullum or Deep Creek This has not been located

When Gregory chose the Lilydale beds as the type strata for the Yeringian Series he did not define the limits of that series It is suggested that the Warrandyte South Quarry conglomerate (a clear field horizon) may mark the lower limit of the type Yeringian Series Selwyn (1856 p 12) says The before mentioned fossiliferous limestone breccia and conglomerates are the only beds of a decidedly marked character in the whole area which can be taken as a geological horizon and by means of which we may hope eventually to subdivide the palaeozoic strata of the Yarra basin into their upper and lower portions

Another question to present itself is where if at all the conglomerate outcrops on the other side of the synclinorium which encloses the Yeringian beds of the Lilydale Seville and Killara districts? Attention is drawn to the conglomerate at Narbethong mentioned by Junner (1914*b*) and Edwards (1932) From this locality fragmentary fossils of a Yeringian character were obtained (Edwards 1932 pp 52 53)

The conglomerate at Warrandyte South may be compared with the Yeringian basal conglomerate and grits of the Walhalla synclinorium described by Herman (1901), Whitelaw (1916), Junner (1920), Baragwanath (1925) and Skeats (1928). Lenticles of limestone are associated with these beds. A conglomerate at Heathcote has been regarded as basal to the Yeringian Series (opinion quoted by Thomas, 1937, p. 67).

Like the Walhalla basal conglomerate and grit, that at Warrandyte South Quarry contains limestone, although in this case it is decalcified in the exposed part. To the south, half a mile west of the Scoresby State School, the Geological Survey collected in 1927 some fossils in impure barytes which were considered to be replacements of limestone fossils. Dr. Dorothy Hill examined these but was not able to discover in them any sure coralline structure. It is interesting in this connection to note the recording from Woori Yallock of calcareous fossils in barytes by Mitchell (1930). Through the kind help of Mr. F. S. Colliver, who assisted Mr. Mitchell in the collection of these fossils, I was enabled to examine the specimens referred to in Mitchell's paper. They include the following forms:

Favosites sp.

Lindstroemia cf. *yeringae* Chapman.

Orthoceras sp.

Conularia sp. (fragment carrying typical ornament).

Beyrichia sp.

Numerous crinoid stem joints.

Brachiopod fragments.

Thus in the Yeringian Series of the Lilydale and adjacent areas there is pure limestone at Cave Hill, impure limestone (60 per cent. silica, 30 per cent. calcium carbonate) at Seville (Cress well, 1901), decalcified limestone in the Warrandyte South Quarry conglomerate, limestone replaced by barytes at Woori Yallock, and possibly the same at Scoresby. According to Gregory (1903, p. 170) the limestone occurrences are characteristic of the Yeringian strata.

The Thickness of the Type Strata.

Selwyn (1852) was the first to publish data concerning the structure of the type Yeringian area. He made a chained and levelled section from 1½ miles west 15 degrees south of Kinlochue Inn, Sydney road, Parish of Mickleham, to Mount Corhanwarabul, near Mount Dandenong. This section showed a large synclinal structure through the Lilydale district. Gregory (1903) called this the "Lilydale Synclinal", making the following comments: "East of this Melbourne fracture zone the beds have

a regular dip to the west This slope is a part of a great anticlinal, of which the axis passes through Warrandyte Along this anticlinal axis there is another line of contortions and faults, along which occurs a series of auriferous quartz reefs The eastern leg of the anticlinal is much steeper than the western and beyond it we come to the great synclinal which passes through Lillydale and Yering We will therefore call it the Lillydale Synclinal Jutson (1911) worked out the structure of the Warrandyte anticlinorium (to the west of Lilydale) and computed the thickness of the rocks on its eastern limb as being between 14 000 and 15 000 feet Later Junner elucidated the structure of the rocks to the north west (1913) and north (1914) of Warrandyte Thomas (1939 p 62) contributed the following comment on the structure of the rocks Between the Starvation Creek and the Lilydale outcrops the general structure seems to be synclinal and this may be termed the Lilydale Warburton synclinorium The graptolite localities at Macclesfield show more complexity than is indicated in this general statement and it may be advisable to separate the Lilydale from the Warburton synclinorium In any case the extension eastwards of the Walhalla beds is a great help in picturing the general structure of this part of Victoria which forms the Lilydale synclinal of Gregory West from Lilydale the principal anticlines are those of Warrandyte Templestowe and Whittlesea and in each of these Melbournian fossils have been recorded It is a sad commentary on the state of our knowledge that we are unable to show the boundary between the Melbournian and Yeringian in this part of Victoria i e between the type areas One finds it difficult to follow Thomas interpretation of the structure between Starvation Creek and Lilydale To begin with these two localities comprise beds of different ages The Starvation Creek beds are Jordanian while the Lilydale beds are Yeringian The Tertiary screens part of this section but to the north the Yeringian beds on the View Hill Creek give evidence of their continuance Probably there is a synclinorium between Warrandyte and Warburton as already suggested

The wide extent of the Yeringian beds may well be due to their repetition caused by a strongly pitching anticlinorium which brings up Melbournian beds in the Macclesfield area Edwards (1940) surmised the presence of a brachy anticlinorium This will be proved if Yeringian beds are found to the south Hall (1914) recorded ***Monograptus priodon*** from Macclesfield Mr R A Keble and the present writer found ***Monograptus*** on a road which proceeds west from the Macclesfield Woori Yallock road on the north side of allotment 98, Parish of Nungana The specimens were obtained from a cutting on a rise about $\frac{1}{2}$ mile west from the Macclesfield Woori Yallock road These ***Monograptus*** beds are Melbournian and occur on an anticlinal axis

Further north at Yellingbo Yeringian fossils have been collected, viz

Anoplia australis sp nov

'Chonetes' bipartita Chapman

Nucleospira australis McCoy

Hyolithes sp

The locality is a low cutting on the road running west from the picnic ground beside Woori Yallock Creek, about ¼ mile from the creek The dip is 53 degrees northerly and the strike east 15 degrees north

In the quotation already given, Thomas states that Melbournian fossils have been recorded in the Warrandyte anticline Chapman also made this claim (1914*a* p 209) The present writer (1940*b*) has shown that the fossils from Anderson's Creek do not determine the age of the beds, and further (1941) that there is a conglomerate with Yeringian fossils at or near the axis of the Warrandyte anticline The Anderson's Creek conglomerate (Selwyn and Ulrich, 1866 p 12 Murray 1887 p 44, Jutson, 1911, p 521) is apparently the same as that at Warrandyte South Quarry The same *Spirifer,* bryozoa and crinoids are found at both localities The conglomerate appears to be repeated over the small anticlines and synclines which crown the Warrandyte Anticline in the vicinity of the Warrandyte township Thus the conglomerate is about the oldest horizon on the Warrandyte anticline, which is therefore Yeringian and not Melbournian as formerly supposed

Gregory (1903 p 172) was surprised that the Lilydale beds could not be found on the western limb of the Warrandyte Anticline They are not repeated there the reason being that there is too great a thickness of rocks on the eastern side for all of them to be repeated on the rising synclinorial folds of the western side Jutson (1911 p 532) found a difference in the thickness of beds on the two limbs of the anticline As Gregory and Jutson noticed, the dips on the whole are steeper on the eastern side than they are on the western side Unfortunately, the rocks from the axis of the Warrandyte anticline as far as the Brushy Creek escarpment are practically unfossiliferous, these are the beds which are repeated on the other side of anticline In an earlier paper the author (1940*b*) described some laminated fossiliferous quartzites from the Yarra-road (locality 19 on the map) Similar beds occur in a road cutting at the southern end of Dublin-road, Ringwood East, and in cuttings at the northern ends of Lumm's and Jell's roads, near Wheeler's Hill These contain the same kinds of fragments seen in the Yarra-road rock, but only crinoid stem joints were definitely identified However, it seems likely that these are three outcrops of the same strata The matrix is a particularly distinctive one This same matrix

(which is presumed to be the same strata) has been found near the axis of the Bulleen Syncline viz on Williamson s road ½ mile north of its junction with the road proceeding north from Doncaster (Military Map reference 157 409) At this locality the following fossils have been found

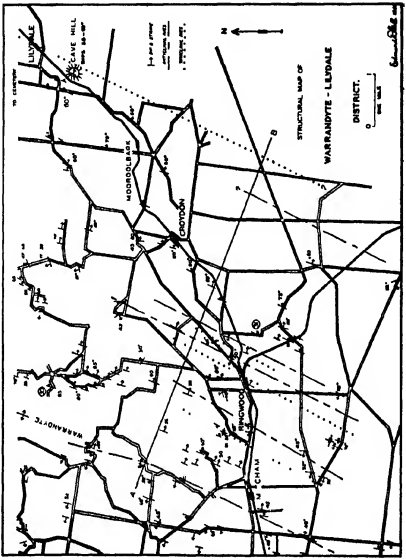
Nucleospira cf *marginata* Maurer

Chonetes sp

Abundant brachiopod and crinoid fragments

At the four localities where this same matrix is known the crinoid stem joints are common and of a small diameter with a simple pattern This may be considered to be characteristic of the beds and a help in correlation Thus there is some structural lithological and palaeontological evidence for assuming that the almost unfossiliferous beds from the axis of the Warrandyte Anticline to the Croydon scarp are the beds repeated on the western limb of the anticline Because of the mounting of the folds in anticlinorial fashion to the Templestowe anticline on which the oldest beds of the series outcrop the fossiliferous Lilydale beds do not appear again That the beds of the Temple stowe Anticline are the oldest is shown by the collection of *Climacograptus* and *Diplograptus* from the Diamond Creek mine (Junner 1913) and of *Illaenus jutsoni* from west of Temple-stowe (Chapman 1912) This palaeontological evidence agrees with the conclusions reached from the geological sections drawn by Selwyn (1852) Junner (1913) and Nicholls (1930)

The map accompanying this paper shows a number of features not previously known The mapping of the area has shown that the principal structures shown by Jutson are substantially correct The Warrandyte Anticline and the Bulleen Syncline have been traced southwards to where they disappear under the Tertiary sands in the vicinities of Notting Hill and Carnegie respectively The Warrandyte Anticline passes through Springvale road at Tunstall about half way between Canterbury road and Central road (the next parallel road further north) Passing through Tally Ho it crosses Waverley road between the termini of Stephenson s road and the road just east of it which runs from Waverley road to Ferntree Gully road at Notting Hill On this last mentioned road easterly dips appear in a road cutting just north of Scotchman s Creek while a few hundred yards further west there are westerly dips in a big quarry (marked on the Military Map) Between these two adjacent points the axis of the Warrandyte Anticline passes The Bulleen Syncline cuts Serpell road at Templestowe about half way between William son s road and Church road (the next parallel road further east) Further south it runs through Mont Albert in the vicinity of the railway station Further south still it crosses the railway line between the Burwood and Ashburton railway stations



The roads and railways have been drawn from the Military Map (Ringwood Sheet, 1935). The dips and strikes were measured during the past two years, and 7 degrees has been added to the magnetic readings as the map is meridional. The area of structure actually mapped extends for some miles in all directions beyond the borders of the map in fig. 2. Only the mapping needed to indicate the thickness of rocks in the synclinorium is presented. Some other data are provided in the text. A few dips and strikes have been taken from the map of Ringwood and Warrandyte by Moon (1893). Some dips and strikes in the northern part of the area are readings kindly made available for me by Dr. F. A. Singleton. The numbers 30 and 31 refer to the fossil localities "Warrandyte South Quarry" and "Dublin Road, Ringwood East" respectively. These numbers follow on those given on a previous map (Gill, 1940*b*, fig. 1, p. 252). The position of the axes of the synclines and anticlines are only approximate in some cases. However, the detailed evidence of dips and strikes is given so that the extent of possible variation is clear.

The exact location of the Lilydale Syncline is not known, and so it is marked with a question mark on the map. The text provides knowledge of its location further to the north and it is surmised that it continues in the same general direction to the south. The westerly dip in the south east part of the map suggests the presence of an anticline but the flat country further north is devoid of outcrops, so the axis shown in the map is marked with a query. This part of the mapping is unsatisfactory, but all the data available have been collected.

Nicholls (1930) has traced the Blackburn Anticline as far south as Oakleigh. Its eastern limb is seen in the north as strong easterly dips on both sides of Blackburn road in a cutting marked on the Military Map (reference 422 380) 1½ miles north of Blackburn. The anticlinal axis can be seen (not marked on Nicholls map) on Burwood road half a mile west of Middle borough road. At the west end of the cutting in which this axis appears there is a decomposed dyke 18 inches wide containing whitish phenocrysts. It is associated with a change of dip from 52 degrees west to 18 degrees west. The Ringwood Anticline has been traced southwards through Vermont and Glen Waverley to Springvale.

From the better known structures further west we come to Lilydale itself. Gregory gave the name Lilydale Synclinal to the synclinorium enfolding the Yeringian type strata. I propose that the name Lilydale Syncline be given the structure in which are the well known Lilydale limestones. This syncline is a little east of Yarra Glen in the north (where there is a strong southerly pitch) west of Flowerfield Quarry west of Yering Railway Station and a little to the east of Cave Hill Quarry. The comparatively low dips at north of Lilydale Flowerfield Quarry and Yering Railway Station may be due to proximity of the synclinal axis. The buckling of the strata seen at the northern end of Cave Hill Quarry where the dip is lessened from 60 degrees to 35 degrees may be due to the same cause.

Jutson (1911) has described a zone of closely approximated anticlines and synclines at Warrandyte. A similar zone occurs at Yering Gorge and another at Ringwood. Last most of the structure of the last named area appearing on an old Geological Survey map (Moon 1893). A fold not previously recorded has been observed in the cutting on Victoria road just north of the Lilydale cemetery. These beds dip to the west while the strata in the cemetery dip to the east. At the adjacent locality west of Lilydale Cemetery (see map Gill 1940*b*) the rocks as far as can be ascertained also dip to the east. The rocks are decomposed but a harder band of quartzitic sandstone with its fossils gives a fairly definite indication of an easterly dip. Further west at Ruddock's Quarry easterly dips occur. To the south there are a number of outcrops yet no sign of this anticline can be found unless the westerly dip at Boronia shown at the southern limit of the map is a continuation of the same structure. At the fossil locality north of Lilydale there is a fauna comparable with that at 'Flowerfield' quarry and cutting. However the first named locality is more than a mile west of Flowerfield. It may be that the anticline observed in the Victoria road cutting continues to the north and that over it the north of Lilydale horizon is repeated at Flowerfield. Paucity of outcrops prevents the observation of detailed structure in this area.

In the area under consideration a feature of some note is the marked difference in physiography between the country south of the Mitcham axis (Hills 1934 p 174) and that north of it This is very noticeable if a contoured map such as the military map for Ringwood is examined In the north the contour lines are crowded together while in the south they are much more spaced The general lithology of the northern area is correspondingly different from that of the south The rocks of the former area are much more indurated Whitelaw (1895) explained this as being due probably to the proximity of an intrusive igneous mass Dykes are common in the area It is noticeable that the gold mining fields (Warrandyte and Queenstown) are restricted to the indurated country To the many records of dykes already made two more are now added in view of their interest and significance First there is a dyke of sericitized felspar porphyry (Univ Coll Rock Sections No 5185) in the Yering Gorge where after half a mile of straight course the river turns east at right angles in a series of rapids (Military Map reference 342 515)

The second dyke is of quartz porphyry and outcrops on the Brushy Creek road near the River Yarra at the northern extremity of the Brushy Creek escarpment It is at the top of the hill which slopes down steeply to the river on the north and to Brushy Creek on the east This dyke is at the northern end of Jutson s Brushy Creek Fault (Jutson 1911) the existence of which was questioned by Hills (1934) This dyke accounts for the supposed larger throw of the fault at this point However if the fault is a dip slip strike fault as thought by Jutson and the throw of the fault is of the dimensions he describes then even if it is present it will not affect very much the computation of the thickness of the strata seeing that such a great thickness of rocks is involved An examination of the area has revealed no major faulting If the Warrandyte South Quarry conglomerate is regarded as the base of the Yeringian strata and the thickness of the series measured along the line A—B on the map (fig 2) the series is seen to be of considerable thickness The average dip is estimated at 45 degrees although often the dips measured were in the vicinity of 60 degrees there were many of about 45 degrees and quite a number lower still (e g Ruddock s Quarry in the vicinity of Ringwood Wonga Park Warrandyte road and in the vicinity of Mitcham) There are also occasional rolls or monoclines as seen in the big quarry on the N E side of Loughnan s Hill Ringwood and in the quarry off the Heidelberg road west of Warrandyte In addition there are minor folds (see S W area of map) to take into account The almost east west strike seen half a mile north of Ringwood suggests a small pitching fold The sum distance of country over which easterly dips prevail is estimated from present evidence as approximately 4 3 miles This gives a thickness of

3 04 miles of strata or 17 000 feet This must be regarded as the maximum thickness, the actual thickness being quite probably less than this figure Were it not for Moon s map (1893) we would not now be aware of the structure which exists at Ring wood East There were formerly brick pits and a kaolin mine in that area which facilitated the study of the structure It may be noted that Selwyn (1852) shows a west dip on the Brushy Creek west of Lilydale The author has been unable to detect the syncline which such a dip infers There is so much alluvium in the area that it screens the bedrock and the gentle hillslopes provide no instructive outcrops There are other considerable areas where no outcrops are to be found The possibility of much more structure existing than has been found must be borne in mind The seeming absence of structure between Croydon and Lilydale is remarkable as there are signs of folding further north (Victoria road cutting near Lilydale cemetery) and further south (Boronia) Moreover on the eastern side of the Lilydale syncline there are folds not far from the axis as can be seen north of the toscanites The thickness of rocks in the Lilydale synclinorium may then be regarded as being between 10 000 and 15 000 feet but more outcrops are needed for a more accurate calculation

This thickness of type Yeringian strata may now be compared with the thickness of Yeringian rocks in other parts of the State

(*a*) Walhalla —In this district there is a thickness of 10 000 feet of Yeringian beds (Baragwanath 1925) As these beds lie in a synclinorial fold their precise original thickness cannot be measured This applies to most of the Yeringian deposits

(*b*) Heathcote —There is a thickness of 12 000 feet above the Melbournian according to Thomas calculations (1937 p 64) The top of the formation is faulted out of sight so that the full thickness of the series is not known The Dargile beds are obviously Melbournian as is shown by their graptolite content The Mt Ida beds are typically Yeringian In between the Dargile beds and the Mt Ida beds are the McIvor beds the precise correlation of which is not yet clear They may correspond to the lower unfossiliferous strata of the type series or they may constitute a more littoral facies of the Jordanian much of which is pelagic or thirdly they may prove to be correlative with both However shelly beds in the Jordanian have only recently been discovered and the fauna of the McIvor beds at Heathcote has not yet been worked out so no dependable conclusions can be reached

(*c*) Whittlesea —Jutson (1908) computed the thickness of the Yeringian rocks at Whittlesea to be 750 feet The original thickness of the series in this area cannot be accurately estimated

because the extant beds are a remnant preserved in a synclinal structure Nevertheless the actual thickness at present persisting appears to be more than Jutson stated The so called Passage Beds are definitely Yeringian as is plainly indicated by the presence of *Pleurodictyum megastomum Strophcodonta alata Actinopteria boydi* &c Indeed all the specific determinations given by Chapman (p 221) in his appendix to Jutson s paper of fossils from the Yeringian beds at Whittlesea (except *Plagiorhyncha decemplicata* which is also Melbournian) are contained in the beds he classifies as Passage Beds (p 220) In addition there is a number of other definitely Yeringian forms as *Strophcodonta alata Rhynchotreta cuneata Actinopteria boydi Phacops* cf *sweeti* and *Dalmanites meridianus* Moreover Jutson has drawn a fault in his section where the dips on his own map show an anticline to be present apparently with a pitch to the north The difference in strike on the two sides of the anticline to which Jutson appeals as evidence of faulting is no doubt due to the asymmetrical character of the pitching anticline the dips being 8 degrees and 10 degrees on the west side whereas they are 40 degrees and 50 degrees on the east side The pitch would give the differential strikes The most variant strike (N 40 degrees E) is on the side of the structure which has the low dips this is to be expected if the foregoing interpretation of Jutson s map is correct

Recently a traverse of Jutson s section was made by Mr R B Withers and myself West of the Eden Park road at a point just south of the bend to the east a big washout in the creek showed a strong easterly dip prevailing in the bedrock An easterly dip was also observed on the Eden Park road a little north of the bend referred to The creek outcrop shows that the axis of the anticline (which occurs where Jutson has a fault) does not run north–south but veers to the west more or less parallel with the axis of the Whittlesea anticline This accords well with the dips shown to the north of Jutson s map The strike of the beds indicates that this holds also for the axis of the Merriang syncline One implication of this revised picture of the structure is that Jutson s localities VI and VII are not two points of outcrop on the same line of strike (as shown on Jutson s map) but outcrops of the same bed on the two sides of an anticline Locality VI is nearer the axis than locality VII because of the much higher dips on the east side of the anticline If all the beds from the axis of this anticline to the axis of the Merriang syncline are Yeringian then there is a thickness of some 1 200 feet present

(*d*) Kinglake —Mr R B Withers informs me that there is a great thickness of Yeringian rocks in this area but the actual figure has not yet been worked out

The Age of the Type Strata.

The following table sets out the ages attributed to the type Yeringian strata by various authors —

TABLE 1

Author	Locality	Attributed Age
Selwyn 1852	On line of section	This series contains numerous fossils of Silurian and Devonian forms
McCoy 1876	Sect XII Parish of Yering	Probably identical with the May Hill Sandstone
McCoy 1877	Yering shale	Wenlock — Lower Helderberg
Etheridge 1890	Cave Hill limestone	Upper Silurian i e the present Silurian
Cresswell 1893	Whole series	Silurian
Gregory 1903	Whole series	Silurian
Chapman 1913 p 209	Lilydale shales	Wenlock
Chapman 1913 p 211		Wenlock and Lower Ludlow
Thomas and Keble 1933	Whole series	Wenlock
Withers and Keble 1933 p 23?	Lilydale mudstone	Wenlock
Chapman and Thomas 1935	Whole series	Silurian with Devonian elements
Ripper 1938	Cave Hill Limestone	Lower Devonian
Hill 1939		Lower or Middle Devonian
Jones and Hill 1940		Lower or Middle Devonian

The early computations of age were made on rather slender objective evidence and so the results were necessarily of limited value Later researches appear to have been influenced by these earlier findings Until the recent studies were made, the age of the beds was accepted as Wenlock Although Chapman regarded the Lilydale beds as Wenlock he recognized some Devonian elements in the fauna (1908, p 8 1914*a*, p 232) The acceptance of the Wenlock age determination as a premise by Thomas and Keble (1933) vitiated their argument that the Melbournian series is younger than the Yeringian series The Melbournian beds are certainly younger than Wenlock, as is shown by their graptolite content (Jones, *1927*, Thomas and Keble 1933) However, the Yeringian series is not Wenlock in age—a conclusion upon which Thomas and Keble depended (pp *79* 81) Nevertheless, the implications of their work are important They extended the graptolite evidence brought forward by Jones (1927) and established the Lower Ludlow age of the type Melbournian beds The Yeringian beds overlie the Melbournian strata and therefore must be younger than Lower Ludlow In 1929 when describing the Reefton (Lower Devonian) beds of New Zealand, Allan (1929, p 323) offered a criticism of the age-determination of the Yeringian in these words ' The Yeringian stage in Victoria is not a clearly defined unit and any exact correlation thereof with the Silurian sequence of Great Britain must be considered entirely provisional In this connexion the importance of facies has not been fully appreciated by Australian geologists "

In 1938 when describing the Baton River (Lower Devonian) beds of New Zealand Shirley (1938 p 492) wrote This fact (viz the occurrence of *Pleurodictyum megastomum* and *Receptaculites australis* in Victoria) coupled with the statement mentioned by Dun in the introduction to the present work (viz that the Baton River fossils are comparable with the Yeringian ones) suggests that the Yeringian contains at least one fauna similar to that of the Baton River series Shirley also wrote (p 499) The identity of two species in the Baton River fauna with species from the Yeringian formation of south eastern Australia usually referred to the Wenlock suggests that the age of some portion at least of this formation requires revision

Ripper after making detailed studies of the stromatoporoids of Lilydale (1933 1937*a*) and Loyola (1937*b*) wrote a paper on the stratigraphical implications of this work (1938) She concluded that the Lilydale limestone is probably of Lower Devonian age It is interesting to note that although McCoy referred Yeringian fossils to the Wenlock he considered that to be equivalent with the Lower Helderberg of North America (1877 p 24) Hill (1939) after studying the corals came to the same conclusion regarding the age of the Lilydale limestone as Ripper had done but added that strong Middle Devonian elements were present This finding was accepted only with some degree of reserve It was thought that there may have been instances of precocious evolutionary advance in that habitat but that this advance was confined to those particular ecological conditions In other words it was thought that the limestone lenticle might carry Lower Devonian fossils but that the accompanying shales were Upper Silurian Later the present author wrote a paper (1941) on the *Pinenla Styliolina* beds which he called Jordanian and which come between the Melbournian and the Yeringian series as is clearly seen on the Walhalla synclinorium These beds Chapman formerly considered to be probably Lower Devonian in age (1928) Although he was not right in considering that they came above the Yeringian series yet the fact that he was brought to believe them to be Lower Devonian or at least uppermost Ludlow by reason of their paleontological content is not without significance There is a considerable thickness of these beds in the Upper Yarra district between the graptolite bearing Melbournian rocks and the Yeringian strata As the Melbournian beds are definitely Lower Ludlow and the Jordanian series comes between them and the Yeringian strata then a Lower Devonian age for part at least of the Yeringian series is seen to be not unlikely

However the Lower Devonian age of the Yeringian shales and sandstones at Lilydale can now be demonstrated largely through the discovery of a well preserved faunule at Hull road Mooroolbark (*vide* Gill 1941) It is now possible to correlate the Lilydale beds with the Baton River (Lower Devonian) beds of New Zealand described by Shirley (1938) It should be noted

that Thomas (1937, p. 67) has indicated the Devonian aspect of Yeringian beds at Heathcote. Here follows a preliminary palaeontological survey of some of the fossils which are of special significance stratigraphically.

Phylum PORIFERA.

Class HEXACTINELLIDA.

Genus **Receptaculites** Defrance, 1827.

RECEPTACULITES AUSTRALIS Salter.

(Plate V, figs. 2, 4, 5)

Receptaculites australis Salter, 1859, p 47, pl x., figs. 8-10
Receptaculites australis Etheridge and Dun, 1898, pp. 62-75, pls. viii.-x
Receptaculites australis Chapman, 1905, pp 7-12, pl ii, figs 2, 4-7; pl iii., pl iv, figs. 2-7.
Receptaculites australis Shirley, 1938, pp. 461-463, pl. xl, figs. 1-4.

A specimen referable to this species has been collected from the brownish shales of Hull-road, Mooroolbark The characteristic rhomboidal plates of this fossil are seen in Plate V., fig. 5 The counterpart is reproduced in fig. 4, where the holes representing the pillars of the original sponge can be seen to terminate in the centres of the plates. Fig 2 shows a cross-section of these moulds of pillars Shirley has recorded this fossil from the Baton River beds of New Zealand, and regarded it as a "suggestive link" with Eastern Australia. He comments— "*Receptaculites australis* was regarded by Etheridge and Dun as of Middle Devonian age, although some of their localities suggest a 'Yeringian' age." I agree. Such places are Molong and Wellington in New South Wales. One is not aware of any place where *R australis* has been collected from rocks of Silurian age David (1914, p 265) refers to *Receptaculites* as a conspicuous and characteristic fossil of the Devonian rocks of Burrinjuck and Taemas (N.S.W).

Phylum COELENTERATA.

Suborder TABULATA.

Genus **Pleurodictyum** Goldfuss, 1829

PLEURODICTYUM MEGASTOMUM Dun, 1898.

(Plate IV, figs. 1, 3, 4, 6, 9)

Pleurodictyum ? problematicum Foerste, 1888, pp. 132-5, pl. xiii., fig 22.
Pleurodictyum megastomum Dun, 1898, p. 83, pl 3, fig. 1.
Pleurodictyum megastomum Chapman, 1903, p 105, pl xvi., figs. 2-5.
Pleurodictyum megastomum Chapman, 1921, p 216, pl. ix., figs. 4-6.
Pleurodictyum megastomum Allan, 1929, p 322.
Pleurodictyum megastomum Withers, 1932, pp. 15-21, text-figs. 1-6
Pleurodictyum megastomum Shirley, 1938, pp. 463-464, pl. xl., figs. 5-8

Shirley (1938) has recorded this coral from the Lower Devonian of New Zealand, and has supplemented the developmental series described by Withers (1932). The youngest stage

so far described is the five celled stage mentioned by Shirley A three celled stage from Symes Tunnel Killara is now illustrated (Plate IV fig 6) and the sizes of the corallites suggest the order of development Three celled stages have also been collected from Ruddock's Corner and Dixon's Creek (Military Map Yan Yean 438 602) From the specimens photographed by Shirley and from others in the author's collections it appears that cells four and five are developed at nearly the same time judging by their size Five celled stages have not been recorded previously from Victoria but the author has found such at Hull road Mooroolbark Ruddock's Corner and Wallan road north of Woodstock (Military Map reference Yan Yean 057 742) The largest number of corallites in any specimen so far recorded is sixteen but in Plate IV a 19 celled stage (fig 4) a 22 cell stage (fig 9) and a 28 cell stage (figs 1 3) are shown These three specimens come from Symes Tunnel Killara from Flowerfield' Quarry and from north of Lilydale respectively A 22 cell stage has also been collected from north of Lilydale The examination of a large series of specimens has shown that the surface of the tabula is pustulose over its whole area (*contra* Chapman 1903 p 106) Infiltrations from the surrounding rock often penetrate the cavity left by the leaching away of the coralline material and obscure the pustulosity round the edges of the fossil *Pleurodictyum megastomum* has many *points d'appui* Specimens have been found appended to crinoid stems *Lindstroemia Orthoceras Pleurotomaria* and *Spirifer* (*vide* Plate IV fig 3) As Allan's survey (1929) of *Pleurodictyum* shows the genus is a typically Devonian one *P megastomum* is in rocks of Devonian age in New Zealand which were formerly thought to be Silurian I regard all the *P megastomum* localities so far described in Victoria as belonging to the Yeringian series and to be of Devonian age New recordings of the occurrence of this fossil in the type Yeringian series are Hull road Mooroolbark Melbourne Hill Lilydale Flowerfield Quarry Coldstream and west of Lilydale cemetery Its earliest appearance in the type series is at Ruddock's Quarry (where it is plentiful) and it occurs through to the youngest of the shales at Hull road Mooroolbark It has not been found in the calcareous strata of Cave Hill nor in the plant bearing beds at Hull road Lilydale The beds from the Warrandyte conglomerate as far as Ruddock's Quarry are apparently unfossiliferous and therefore the absence of *Pleurodictyum* from them can be given no significance

Phylum BRACHIOPODA

Genus **Schizophoria** King 1850

SCHIZOPHORIA PROVULVARIA (Maurer)

(Plate VI fig 1)

Vide Maillieux 1936 for synonymy to that date
Schizophoria provulvaria Shirley 1938 p 465 Pl XL figs 10 13

Outline sub circular to transversely oval Ventral valve slightly convex and dorsal valve much more convex than ventral one Ventral valve interior teeth strong and produced into dental plates which diverge at an angle of about 80 degrees The plates continue as low ridges following the perimeter of the muscle impressions The muscle impressions are flabellate and about half the length of the shell Their proportion of width to length is approximately 2 3 Vascular markings generally radial except the two main trunks passing forward from the divaricator impressions As Shirley remarks the structures become thicker and heavier with increasing age No well preserved dorsal valve has been collected but those obtained show the widely divergent crura and crural plates found in *Schizophoria provulvaria* This fossil has been collected from Hull road Mooroolbark Melbourne Hill Lilydale north of Lilydale Wilson s (near Lilydale) Ruddock s Corner and ? Ruddock s Quarry

Schizophoria provulvaria is characteristic of the Silurian and Lower Coblenzian of Europe Its occurrence ranges geographically from the Lower Devonian of England (Lloyd 1936) to New Zealand (Shirley 1938) and its discovery in Victoria now adds another link to the chain of known occurrences Similar species *S striatula* (Ruedemann and Balk 1939) and *S vulvaria* (Schuchert and Cooper 1932) have been recorded from the Devonian of North America Etheridge (1902) has recorded *S* nr *striatula* from Sandy s Creek Gippsland Victoria

Genus **Fascicostella** Schuchert and Cooper 1931

FASCICOSTELLA GERVILLEI (Defrance)

(Plate VI figs 3 5)

For synonymy *vide Shirley* 1938 This species which is a component of the N Z Baton River beds is found in the Yeringian type strata The description given by Shirley (1938, pp 466-467) is applicable to the Victorian specimens which have the same characteristic external ornament and internal structures The furrowed dental sockets can be seen in specimen No 1729 (Reg No Univ of Melb Geol Dept Mus)

Shells referred by Chapman (1914*a* p 224) to *Orthis* ? *actoniae* Sowerby belong to this genus and probably to this species The specimens are in the National Museum and come from Killara (Junction of the Woori Yallock and Yarra) A careful revision of the fauna is beginning to show that there is not present such a mixture of faunas of different ages as was formerly supposed

Schuchert and Cooper (1932 p 130) regarded *Fascicostella* as an essentially European genus It is interesting to find its occurrence in the Lower Devonian of both New Zealand and

Australia *F gervillei* is known from the following localities in the Yeringian type area Ruddock s Quarry, Ruddock's Corner, Melbourne Hill Lilydale and Mitchell s Paddock, Lilydale

Genus **Anoplia** Hall and Clarke 1892 Emended Schuchert 1913*b*

ANOPLIA AUSTRALIS sp nov

(Plate IV fig 8)

Shell small sub semicircular concavo convex Hinge line straight approximating to greatest width of shell Ventral valve convex flatter on lateral areas which extend from the position of the interior lateral septa to the lateral margins of the shell Cardinal extremities approximately right angles Surface smooth Spines absent Cardinal area full width of shell well developed at beak but tapering away towards the cardinal extremities Beak strong fairly sharp projecting beyond the cardinal line Interiorly a long median septum traverses about three quarters of length of valve and terminates abruptly Lateral septa or ridges of similar length to the median septum make an angle of about 45 degrees with the latter Muscle scars not seen Dorsal valve concave with flattened lateral areas corresponding with those of ventral valve Outline same as ventral valve Surface smooth Cardinal area linear Median and lateral septa corre sponding with those of ventral valve Measurements of type specimen Length (excluding beak) 4 mm width 6 mm Discussion The blunt septa seen in this new species are characteristic of *Anoplia* (Schuchert 1913*b* pp 339 340) The lateral septa or ridges apparently enclose the muscle areas They strengthen the shell increase the area for the attachment of muscles and also provide a new angle of muscle attachment Except for the present author s references in recent papers to *Anoplia* sp nov the genus has not been recorded from Australia before (Gill 1940*b* 1941) As far as the writer is aware the genus has not been recorded outside of America before There are two species known (Schuchert and Maynard 1913) *A helderbergiae* belonging to the Lower Devonian and *A nucleata* belonging to Lower and Middle Devonian formations The discovery of *Anoplia* in Yeringian beds is a further indication of their Devonian age and a further link with the American fauna *A australis* is not closely comparable with either of the American species Variation has been noted in the new species in the size of the cardinal angles and so too in the profile of the lateral margin

Occurrence The type specimen (lodged in the University of Melbourne Geological Museum reg No 1720) is from the impure limestone of Seville Quarry (Military Map Ringwood 497 413) This species is common in the type Yeringian strata

and the type is taken from another source because of its preservation of both valves *in situ*. *Anoplia australis* has been collected from the following localities, all of Yeringian age: Ruddock's Quarry, Ruddock's Corner, "Devon Park" North, Victoria-road cutting, Hull-road, Mooroolbark, Syme's Tunnel, Killara, west of Yankee Jim Creek, Watson's Creek (Gill, 1941, p. 158), Howe's Creek Quarry (Parish of Loyola, sect. 132), quarry on track south from Hume Vale–Tommy's Hut road, Kinglake, about one-quarter of a mile west of Tommy's Hut, north of Ruddock's (this is a new locality, consist of a small cutting directly north of Ruddock's Quarry, on the road which proceeds west to Wonga Park from Edward road).

ANOPLIA WITHERSI sp. nov.

(Plate IV, fig. 7.)

This species is similar to *Anoplia australis* except that it possesses in both valves five interior septa instead of three. On each side of the median septum there is an extra septum or ridge between the median septum and the lateral septa or ridges. These accessory ridges are much shorter than the others and do not extend far enough to meet them.

Measurements of type specimen: Length of shell (not including beak) 3.2 mm., width of shell 3.8 mm. The type specimen is lodged in the Geological Museum of the University of Melbourne (reg. No. 1721) and was collected from Syme's Tunnel, Killara.

A. withersi is named after Mr. R. B. Withers, M.Sc., Dip.Ed., who has collected *Anoplia* in the Kinglake district, and kindly submitted the material to the author.

A. withersi is widely distributed but is not so common as *A. australis*. It has been collected from the following localities: Ruddock's Quarry, north of Ruddock's, Ruddock's corner, west of Yankee Jim Creek (Upper Yarra District), Syme's Tunnel, Killara.

Genus **Hipparionyx** Vanuxem, 1842

HIPPARIONYX MINOR Clarke, 1909

(Plate V, figs. 1-10.)

(Plate VI, fig. 2.)

Shirley (1938) has described this species from the Baton River beds of New Zealand, and the Victorian specimens are very similar. Like the Baton River specimens, those now figured have a finer ornament than the ones illustrated by Clarke (1909). Most of the specimens obtained have the same fineness of ornament as those described by Shirley (18 ribs in 10 mm.). Two others have a still further finer ornament of 22 ribs in 10 mm. (*vide* Plate V, fig. 10). Examples of both kinds have been obtained from north of Lilydale. Apparently they are two

varieties of the species *Hipparionyx minor* has been collected from north of Lilydale Wilson s (Cresswell Coll) Melbourne Hill Lilydale Hull road Lilydale and Hull road Mooroolbark The variety of *H minor* with the finer ornament is found in the first and last of those localities One shell figured (Pl V figs 1 10) belongs to this variety and comes from Hull road Mooroolbark It possesses the fine concentric ornamentation absent from the interspaces which Shirley mentions (p 472) Plate VI fig 2 is an internal cast of a dorsal valve from Wilson s Lilydale (in the Cresswell Collection housed in the National Museum) and it possesses an ornament comparable with that of the Baton River forms

Genus **Leptaena** Dalman

LEPTAENA RHOMBOIDALIS (Wilckens)

(Plate V figs 3 and 8)

Leptaena (Leptagonia) rhomboidalis McC y 1877 pp 19 20 Pl xlvi fig 1

? *Leptaena rhomboidalis* Chapman 1913 p 102 Pl x fig 3 *non* pp 103 104 Pl x figs 4 7

As the synonymy of this ubiquitous species is well known it is not given here References to descriptions of specimens in Victoria are alone provided

Description of dorsal valve from Hull road Mooroolbark Shell sub quadrilateral the anterior margin being about parallel to the hingle line Hinge line equal to greatest width of shell Cardinal angles sub auriculate Cardinal area linear Valve slightly concave for approximately three quarters of its length and then deflected abruptly dorsalwards External surface marked by distinct concentric rugae on the flattish posterior part but not on the geniculated anterior portion Very numerous fine radiating striae extend the full length of the shell crossing the rugae without interruption Interior surface finely and closely papillose the papillae being streamlined posteriorly into minute ramps which are aligned more or less with the direction of the external striae Cardinal process double extends beyond the hinge line Shallow crural bases continue as low ridges defining a large pair of posterior muscle scars (posterior adductors) and a much smaller pair (anterior adductors) which lie immediately in front of the former The anterior adductors are separated by a thin median septum which terminates anteriorly in a prominent knob The posterior adductors are separated by a comparatively wide but low median septum After traversing three quarters of the length of the scars this septum lowers rapidly into a well marked depression which further forward gives place to the thin septum dividing the anterior adductors

This shell conforms to the Helderbergian type of *Leptaena rhomboidalis* (Hall and Clarke 1892 Plate VIII figs 20 27 Grabau and Shimer 1909 p 226 fig 273*b*) with well developed

internal features It also has many points of similarity with specimens figured by Barrande from Bohemia (1879 Plate 41 figs 25 and 30)

In 1913 Chapman (*vide* synonymy) claimed to have discovered a denticulate hingle line on a specimen of *Leptaena rhomboidalis* from Loyola The specimen reg No 124301 National Museum probably belongs to this species but the hinge line is not denticu late Chapman also described two other fossils reg Nos 12402 and 12403 as specimens of *L rhomboidalis* showing brachial impressions However the writer does not regard these determinations as correct

Genus **Stropheodonta** Hall 1852

STROPHEODONTA BIPARTITA (Chapman)

(Plate V figs 7 and 9 Pl VI fig 10)

Chonetes bipartita Chapman 1913 pl x figs 8 9 10

This brachiopod does not belong to the genus *Chonetes* because it is devoid of spines Large numbers from many localities have been collected and if spines were present at least the bases of the spines would have been preserved on some of the specimens However the cardinal margins of all are quite smooth

Actually the shell is a *Stropheodonta* having a finely denticu late hinge line This fine denticulation is clearly preserved in the brachial valve which is one of the co types of the species *S bipartita* is of the *Strophomena comitans* Barrande type This latter fossil is a widely distributed Lower Devonian species originally described from Bohemia Besides occurring in Europe it is known from the Lower Devonian of Burma (Reed 1929) A comparable form has been recorded from Indochina (Mansuy 1916 Plate II fig 2 *a* and *b*) It is interesting to note that some of the specimens of *S comitans* figured by Barrande are bipartite (Barrande 1879 Vol V Plate 56 figs 19 20) As in *S comitans S bipartita* also has a denticulate hinge line for approximately half the distance between the umbo and the cardinal extremities Both species are fully papillose interiorly and possess a comparable musculature The two co types and the paratype which Chapman selected when describing *Chonetes bipartita* are all internal impressions The external ornament on both valves consists of about 25 ribs radiating from the umbo with two to six fine intermediate riblets between each pair of ribs

S bipartita is very widely distributed in the Yeringian series and in some places is present in immense numbers (e g Ruddock s Quarry) The species is not known from outside the Yeringian beds and constitutes a good index fossil for the series

Genus **Eospirifer** Schuchert 1913

EOSPIRIFER sp

(Plate VI figs 8 and 9)

The two specimens figured are the only two which have been found They are significant because they are clearly of the *I togatus* (Barrande) type which species is common in the Lower Devonian of New Zealand

Genus **Cyrtinopsis** Scupin 1896

Cyrtinopsis perlamellosus (Hall)

(Plate VI figs 6 7)

Spirifer perlamellosa Hall 1857 p 57 figs 1 2

Spirifer perlamellosus Hall 1859 p 201 pl xxvi figs 1a 1s 2a 2g

Spirifer perlamellosus Hall and Clarke 1894 pp 15 17 pl xxxv figs 7 13

n n *Spirifer perlamellosus* var *densilineata* Chapman 1908*a* pp 223 224 pl iv figs 1 and 2 pl v

Spirifer perlamellosus Grabau and Shimer 1909 p 321 fig 407

Cyrtinopsis perlamellosus Shirley 1938 pp 482 483 pl xliv figs 9 10

Shirley s description is applicable to specimens of the above species collected from Hull road Mooroolbark In Plate VI fig 7 the high cardinal area is seen in a mould which shows horizontal striations those on the deltidial plates being finer than those on the rest of the area Although Hall (1859) does not refer to it in his description he shows in his Plate 26 fig 2*f* that the interior of the ventral valve is papillose in the umbonal region One of our specimens shows a similar papillosity

Chapman (1907 p 239) recorded from Kilsyth *Spirifer perlamellosus* J Hall var nov (= *S sulcatus* McCoy *non* Hisinger) Later (108 p 223) he altered his determination of these fossils to *Spirifer sulcatus* Hisinger sp He wrote In a former paper giving a list of Silurian (Yeringian) fossils from the Croydon district I included a spirifer there referred to as *S perlamellosus* var nov and bracketed it with *S sulcata* The small examples of the new variety *densilineata* show certain marked affinities with those figured by McCoy under Hisinger s specific name and at the time it seemed highly probable that they made a continuous series of one variable species A further examination of a large number of Yeringian spirifers shows however that McCoy was right in regarding his specimens from Yering as identical with Hisinger s species the chief and fairly constant differences between the two forms *S perlamellosus* var *densilineata* and *S sulcatus* being the higher delthyrium the closer lamellation more numerous plications and interrupted striae of the latter The Croydon examples should therefore be referred to *Spirifer sulcatus* Hisinger sp The Kilsyth fossils are not really comparable with the variety *densilineata* because the latter belongs to a different genus The internal and external characters of the Kilsyth fossils show them to belong to *Cyrtinopsis perlamellosus*

McCoy's fossils referred to *Spirifera sulcata* in the Prodromus (1877 p 23) probably should be referred to *Cyrtinopsis perlamellosus* He was inclined to regard the latter as a New York local variety of *S sulcata* The internal structure is not shown in his specimens but the high area and deep sinus are very much like those of *C perlamellosus* found further south in the same series

Chapman (1908*a* p 223) described from the Whittlesea district what he considered to be a new variety of *C perlamellosus* to which he gave the name *densilineata* Actually the specimens are not referable to the genus *Cyrtinopsis* because there are not dental lamellae converging and united with the median septum (Schuchert 1913 p 413) This is seen clearly in Plate IV fig 2 Also the shells are not concentrically marked by strong imbricating lamellae which are abruptly arched in passing over the plications (Hall 1859) This can be seen from Chapman's own photographs (Plate V) More or less concentric rugae are often present on these shells but not lamellae Some of the rugae are the result of crushing The majority are apparently due to irregularity of growth Most of them traverse only a part of the shell Moreover the fine striations are not limited to lamellae as they are in *C perlamellosus* but proceed unbroken down the entire length of the shell (see Chapman's Plate V fig 3) Chapman provides no description of Plate IV on which are drawings of reconstructed shells The drawings show even and regularly spaced lamellae such as do not appear on the type specimen or on any specimens which the author has examined The deltidial plates are much bigger than shown The three specimens shown in the photographs of Plate V are all dorsal valves Chapman's form is referable to the genus *Eospirifer* Schuchert (1913 p 411) The genus is thus defined

Quadrate and alate early Spirifers that are either smooth radially undulate or plicate but without plications on fold and sinus Surface with additional fine filiform radiating striae which may be minutely crenulate or granulose Dental lamellae present Shirley (1938 p 476) has slightly modified and extended this description Chapman's form may now be known as *Eospirifer densilineata* (Chapman)

Genus **Nucleospira** Hall 1859

Nucleospira cf marginata Maurer

(Plate IV fig 5 Pl V fig 6)

Maurer 1886 (not viewed)
Beushausen 1897 p 289 pl v figs 8 12
Shirley 1938 p 481 pl xliv figs 6 8

Judging by Beushausen's figures the Victorian specimens are not specifically separable from Maurer's species They are very like those described by Shirley from the Baton River beds of New Zealand Ventral muscle impressions are similarly striated

and the median septum commonly (but not always) thickens into a bulb at the anterior end Quite often the small oval adductor impressions of the ventral valve are distinctly separated from the divaricators Some of the shells have growth lines on them like those figured by Beushausen The same author states that although *N marginata* is usually transverse oval in outline some of the specimens are longer than broad These variations have been noticed in Victorian specimens McCoy noted this same variation of outline in *N australis* where the sub circular profile is the commoner The measurements of the figured specimens are Plate IV fig 5 5 mm long by 6 mm wide Plate V fig 6 5 mm by 5 mm

N cf *marginata* has been collected from Warrandyte South Quarry basal conglomerate Williamson s road Doncaster north of Lilydale and Hull road Mooroolbark At the last named place this fossil is very abundant Specimens from Warrandyte South Quarry have the same general proportions as those from higher horizons but are typically smaller and the anterior bulbous swelling of the median septum is absent The ventral divaricator scars are striated Other details are difficult to determine because of the poor preservation

Genus **Karpinskya** Tschernyschew 1885

KARPINSKYA (?) FIMBRIATA (Chapman)

Atrypa fimbriata Chapman 1913 p 109 pl xi fig 15

This species is not referable to the genus *Atrypa* because it possesses a dorsal median septum *Karpinskya* is a genus of *Atrypa* like shells having a dorsal median septum The geno holotype *K conjugula* however is elongate while the species under discussion is sub circular in outline and possesses marginal spines Chapman compared his genus with *A hystrix* and *A spinosa* It resembles the former in the development of marginal spines The species is referred with question to *Karpinskya* because although it possesses the characteristic (*vide* Schuchert 1913 p 409) dorsal median septum of that genus it differs in the presence of marginal spines and in its proportions

Karpinskya is a Lower Devonian genus the genoholotype being described from beds of that age in Russia The spinose North American species of *Atrypa* are from Middle and Upper Devonian strata Barrande (1879) figures a spinose sub circular species (*A semiorbis*) from the Lower Devonian of Bohemia (Vol 5 Plate 34 fig 22) The holotype of *Karpinskya fimbriata* is from near Lilydale which is very probably the locality known as Wilson s (for exact location see Gill 1940*b*) In a collection of fossils at the National Museum Melbourne presented by the late Rev A W Cresswell M A there is a specimen of this shell side by side with the specimen of *Hipparionyx minor* figured on Plate VI fig 2 This specimen also comes from Wilson s Some poorly preserved specimens of *K fimbriata* have been found at Devon Park West

From Ruddock's Quarry and Melbourne Hill, Lilydale, there have been collected atrypids with marginal spines. These are flat and somewhat elongated, not globose and sub-circular like *K. fimbriata*.

Phylum PELECYPODA

Genus **Actinopteria** Hall 1859

Shirley (1938) describes *Actinopteria* sp. from the Baton River (Lower Devonian) beds of New Zealand and points out that Pterinoid shells are rare in the Silurian. From the type Yeringian beds the following Pterinoids have been described:—

Actinopteria textuata (Phillips), *A. boydi* (Conrad), *A. asperula* var. *[illegible]* Chapman, *L[illegible]pteria* cf. *[illegible]* Hall.

These were described by Chapman (1908*b*). Pterinoid shells are common at north of Lilydale, Wilson's, Melbourne Hill, Lilydale, and Kilsyth. They constitute a characteristic element of the Yeringian fauna.

Genus **Cypricardinia** Hall 1859

This genus is common in the higher horizons of the type Yeringian series. Chapman (1908*b*) has described *Cypricardinia contexta* Barrande from three localities in the Lilydale district. Shirley has recorded the genus from the Lower Devonian of New Zealand. Barrande's species referred to above occurs in the Lower Devonian of Bohemia.

Phylum TRILOBITA

Genus **Calymene** Brongniart 1822

Sub-genus GRAVICALYMENE Shirley 1936

Calymene angustior Chapman, 1915, p. 164-6, pl. xv, figs. 8-10.
Calymene (Gravicalymene) ? angustior Shirley, 1938, p. 487, pl. xliv, fig. 17.

Shirley's sub-genus covers a clearly demarcated group which apparently represents a definite line of evolutionary development. It is therefore deserving of generic rank. *Gravicalymene angustior* has been collected in the type area from Ruddock's Quarry, Ruddock's Corner, north of Ruddock's and Mitchell's Paddock, Lilydale. It is a conspicuous part of the trilobite assemblage. Shirley has described this species from the Lower Devonian beds at Baton River in New Zealand. He suggests (p. 487) that *G. australis* is conspecific with *G. angustior*. A similar form, *G. cootamundrensis*, has recently been described from N.S.W. (Gill 1940*a*). Mansuy's *Calymene maloungkaensis* from Indochina belongs to this genus and has affinities with the Australian species (Mansuy 1916, Plate IV, figs. 4*a*-*q*).

Genus **Goldius** De Koninck 1841

Shirley (1938) records this genus from New Zealand, remarking that it has not been recorded from the austral Lower

Devonian and so provides further evidence of the biological separation of that province This separation is a very marked one and forced itself on the attention of the present writer when investigation of the Lilydale fauna was first undertaken

The palaeontological data set out in the preceding pages reveal a definite connexion between the Baton River (Lower Devonian) beds of New Zealand and the type beds of the Yeringian Series This evidence is summarized in the following list of fossils common to both deposits

> *Receptaculites australis* Salter *Pleurodictyum megastomum* Dun *Schizophoria provulvaris* (Maurer) *Fascicostella gervillei* (Defrance) *Hipparionyx minor* Clarke *Nucleospira* cf *marginata* Maurer *Cyrtinopsis perlamellosus* (Hall) *Calymene (Gravicalymene) angustior* (Chapman)

Further evidence of Devonian age is provided by the presence of

> *Anoplia* sp *Karpinskya* (?) sp A *spirifer* of the *E elongatus* (Barrande) type *Stropheodonta* of the *S comitans* (Barrande) type

The foregoing data demonstrate the Devonian age of the Lilydale shales and sandstones and they show that in part at least they can be correlated with the Baton River beds of New Zealand

Shirley (1938 p 490) commented on the presence of *Hipparionyx* and *Cyrtinopsis* as forming a strong link with the North American deposits since these genera do not occur in the European Lower Devonian The presence of *Anoplia* in the Yeringian beds strengthens that correlation for that genus is known only from America and Australia

The finding of a Devonian age for the Lilydale shales and sandstones is supported by work on the limestone facies by Dr Ripper (Stromatoporoids) and Dr Hill (Corals) Originally it was thought that all the limestone deposits of the Yeringian Series in various parts of Victoria belong to the same horizon Murray (1887 p 45) stated that the various limestone patches are clearly identical with one another in geological position Dun (1889 p 70) wrote of the Loyola limestone It is probably of the same age as the Lilydale limestone Chapman (1914*a* p 211) thought the Seville limestone to be equivalent in age to the Lilydale lenticle However Ripper and Hill have shown that the Loyola limestone is somewhat older than that at Lilydale The Seville limestone is probably also older than the Cave Hill deposit The limestones of the Walhalla synclinorium occur as lenticles in the basal grits (Whitelaw 1916 p 8) and should probably be correlated not with the Cave Hill limestone but with the decalcified limestone of the basal conglomerate seen in the Warrandyte South Quarry This finds some support from the statement of Jones and Hill (1940 pp 200 203 206 208) that the limestone at Cooper s Creek (tributary of the Thomson River, Gippsland) is Silurian or perhaps Devonian

Summary and Conclusions

1 The Warrandyte South Quarry fossiliferous conglomerate is suggested as a base for the type Yeringian Series

2 The thickness of the strata as measured from the con glomerate is estimated as being somewhat less than 17 000 feet Lack of outcrops in some areas prevents a precise calculation The general form of the structure is synclinorial The eastern side of the synclinorium is largely screened by the Upper Devonian igneous rocks of the Dandenong Mountains complex

3 The age of the shales and sandstones is shown to be Devonian In part at least these beds can be correlated with the Baton River (Lower Devonian) beds of New Zealand described by Shirley The fauna reveals definite affinities with the European and North American Lower Devonian faunas Three genera found in the North American but not European Lower Devonian are present in the Lilydale beds viz *Hipparionyx Cyrtinopsis* and *Anoplia* There is little connexion with the austral Lower Devonian faunas of South America and South Africa The wide admixture of Wenlock to Devonian elements earlier claimed for the Yeringian fauna is found to be untenable upon the re study of the fauna

Acknowledgments

In addition to the acknowledgments made in the text I wish to express my appreciation of the help of Dr I A Singleton who accompanied me in the field on some occasions Drs I S Hills and A B Edwards and Mr G Baker M Sc have kindly examined the intrusive rocks mentioned in the paper I wish to express my indebtedness also to Mr I A Baillot of the Mel bourne Technical College who has taken much interest in the special problems associated with the photography of palaeonto logical specimens Nearly all the photographs in the accompanying plates are his work None of the photographs has been re touched

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Description of Plates

PLATE IV

FIGS 1 and 3 *Pleurodictyum megastomum* Dun from North of Lilydale—counterparts Fig 1 mould of corallites (1711) Fig 3 epitheca on *Spirifer* (1712) × 2 5

FIG 2—*Eospirifer densilineata* (Chapman) from Cemetery Hill Road Whittlesea showing diverging dental lamellae (1715) × 1 1

FIG 4—*Pleurodictyum megastomum* Dun Mould of corallites from Syme's Tunnel Killara (1713) × 1 5

FIG 5—*Nucleospira* cf *marginata* Maurer Internal cast of ventral valve from Hull Road Mooroolbark showing striated divaricator scars small oval adductor scars growth lines and expanded anterior end of median septum (1726) × 4 approx

FIG 6 *Pleurodictyum megastomum* Dun Three celled form from Syme's Tunnel Killara (1714) × 2

FIG 7—*Anoplia withersi* sp nov from Syme's Tunnel Killara Holotype Internal cast ventral valve (1721) × 4

FIG 8—*Anoplia australis* sp nov from quarry in impure limestone Warburton highway Seville Holotype Internal casts of dorsal and ventral valves (1720) × 4 approx

FIG 9—*Pleurodictyum megastomum* Dun Flowerfield Quarry [14103] × 2 approx

Plate V

Figs 1 and 10—*Hipparionyx minor* Clarke Counterparts of ventral valve from Hull Road, Mooroolbark Fig 1 internal cast (1731) Fig 10 external mould (1732) × 2

Figs 2 4 5—*Receptaculites australis* Salter from Hull Road Mooroolbark Fig 2 cross section of moulds of pillars (1716) Figs 4 and 5 counterparts showing rhomboidal plates (1716, 1717) Fig 4 shows how the pillars terminate in the centres of these plates (1716) × 2

Figs 3 and 8 *Leptaena rhomboidalis* (Wilckens) counterparts from Hull Road Mooroolbark (1718 1719) × 2 approx

Fig 6—*Nucleospira cf marginata* Maurer from Hull Road Mooroolbark (1727) × 4 approx

Figs 7 and 9—*Stropheodonta bipartita* (Chapman) counterparts showing internal casts (1725) and external moulds (1724) respectively Note denticulate hingeline Specimens from Yellingbo × 3 approx

Plate VI

Fig 1—*Schizophoria provulvaria* (Maurer) Internal cast of ventral valve from Hull Road Mooroolbark (1733) × 2

Fig 2—*Hipparionyx minor* Clarke Internal cast of dorsal valve from Wilson s, Lilydale [14104] × 1 approx

Figs 3 4 5—*Fascicostella gervillei* (Defrance) from Melbourne Hill Lilydale Figs 3 (1728) and 4 (1729) ventral internal casts Fig 5 internal cast of dorsal valve (1730) × 2

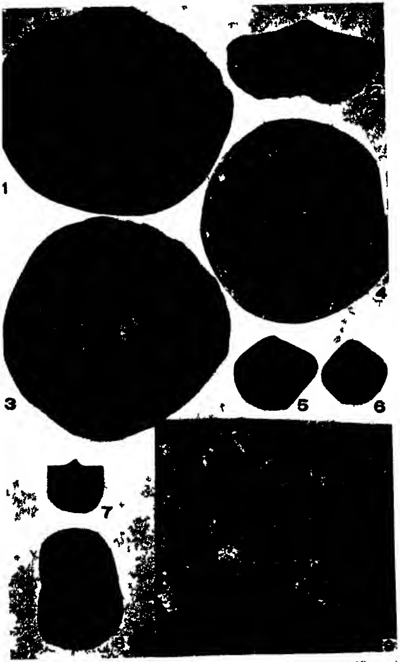
Figs 6 and 7—*Cyrtinopsis perlamellosus* (Hall) from Hull Road Mooroolbark Fig 6 external mould dorsal valve (1722) Fig 7 internal cast of ventral valve with the right half broken away showing the striate cardinal area and the dental lamellae converging to unite with the median septum (1723) × 2

Fig 8—*Eospirifer* sp from Lilydale Mudstone ' (Cresswell Coll) [14105] × 1 approx

Fig 9—*Eospirifer* sp from Ruddock s Quarry [14106] × 1 approx

Fig 10—*Stropheodonta bipartita* (Chapman) Enlargement of Pl V fig 9 to show detail of ornament and denticulate hingeline (1724) × 7 approx

Note—In all descriptions of plates the numbers in rounded brackets are registered numbers of the University of Melbourne Geology Department Museum Those in square brackets are registered numbers of the National Museum Melbourne



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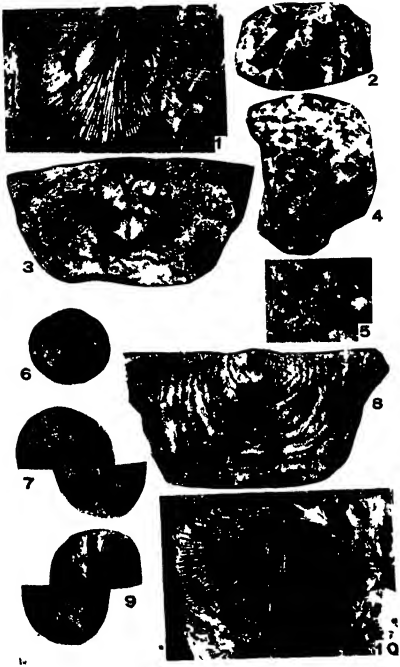
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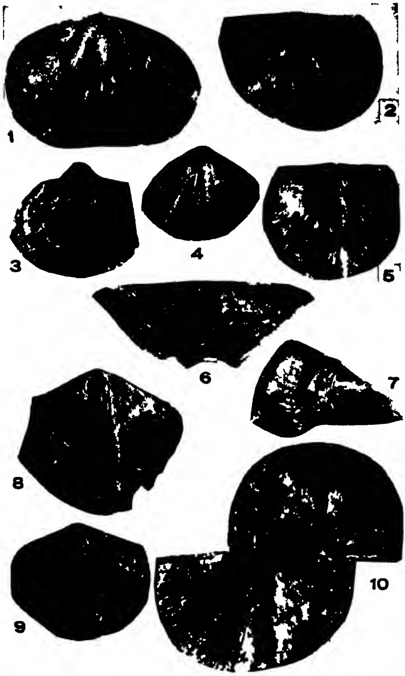
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[Proc. Roy. Soc. Victoria, 54 (N.S.), Pt. I., 1942.]

Art. IV.—*The San Remo Peninsula.*

By A. B. EDWARDS, Ph.D., D.I.C.

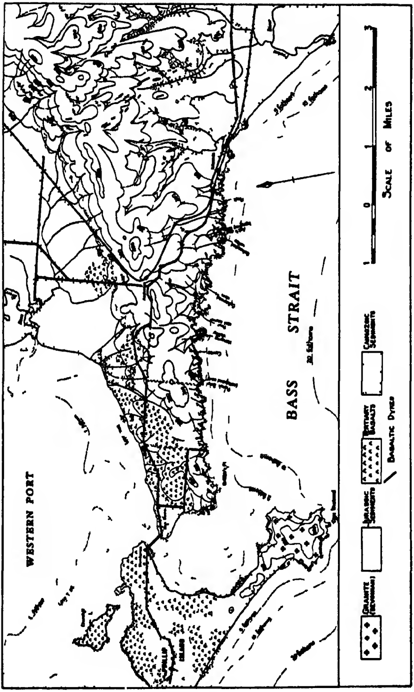
[Read 12th June, 1941; issued separately 15th April, 1942.]

Contents.

Introduction.

The San Remo Peninsula is that arm of the land, about six miles long and from one to one and a half miles wide, that extends westwards from the south-eastern corner of Western Port Bay (Text Map). It is composed of Jurassic sediments, capped by Tertiary gravels and basalts (Stirling, 1893), and consists of a tilted horst, which is the westerly extension of the Bass Ranges, one of the major fault blocks of the South Gippsland Highlands. On the north side it is bounded by the Bass Fault, while on its southern side it was originally bounded by the Kongwak Fault (Hills, 1940, fig. 347). The throw of these faults died away towards the west. This is shown by the decreasing height of the Bass Range horst in this direction, from well over 1,000 feet above sea-level at Strezlecki to about 900 feet at Krowera, and Bass Hill, 600 feet at Steenholdt's Hill, 400 feet near Kilcunda, and to about 200 feet at San Remo.

The horst is tilted to the north at an angle of about 5° throughout the Peninsula. This is proved by the disposition of the Tertiary basalts, which occur only on the northern side of the Peninsula, sloping down from about 200 feet above sea-level on the hill tops to below sea-level on the northern coast, as a capping on the Jurassic sediments. At the eastern end of the Peninsula, near the Anderson Railway Station, cuttings along the Melbourne-Wonthaggi road where it climbs the Bass Scarp show that the basalt occurs only on the lower slopes of the Scarp, overlying a tilted Jurassic surface. This tilt must have caused the drainage to develop chiefly as north-flowing, back-slope streams, with much shorter streams flowing southwards over the steep southern scarp. The south-flowing streams, with their steeper gradients, have cut down rapidly into the Jurassic sediments exposed in the scarp, and by headward erosion have



Text Map Geological Sketch Map of the San Remo Peninsula

undermined and stripped off the basalt from the southern side of the block, where its former presence is revealed only by dykes. As the scarp matured, the greater vigour of the south-flowing streams caused the divide to migrate northwards to its present position close to the northern margin of the horst. Ferguson (1909) notes that the tilt persists throughout the Bass Range (Quarter Sheet 67 N.E.), where many of the individual hills show a gentle dip slope to the north and a steep scarp to the south, and that it steepens towards the northern edge of the range, suggesting that in this region a monoclinal structure is associated with the Bass Fault. The author has noted almost vertical beds adjacent to the scarp near Nyora; and a comparable steepening of the northerly dip occurs along the northern coast of the Peninsula.

The surface of the granitic stock that forms the south-eastern end of Phillip Island also slopes to the north at an angle of 5° (Plate VII., fig. 3), and like the San Remo horst the granite is flanked by Tertiary basalts on the north, and ends in steep cliffs 200 to 300 feet high on the south side. This tilted surface must represent an old land surface, since the forces now acting on the granite are not sufficient to erode such a slope. If the line of the Kongwak Fault is continued westwards from Kilcunda, it passes just to the south of the cliffs of Cape Woolamai. It is probable, therefore, that, although the Woolamai granite stock and the basalts to the north of it are now separated from the San Remo Peninsula by a narrow channel about three-quarters of a mile wide (The Eastern Passage), they were once part of the San Remo horst. Under the influence of marine erosion the resistant granite has maintained more or less its original scarp, but the more readily eroded Jurassic strata have been cut back. At the western end of the Peninsula (Griffith's Point) this retreat has been of the order of two miles. At the eastern end (Kilcunda) on the other hand, progradation of the shore has removed the easterly part of the Kongwak scarp from marine erosion. As a result, the southern coast of the Peninsula has slowly retreated hinge-fashion, the pivot being at Kilcunda. This has been furthered by the decreasing height of the original scarp from east to west. The granite stock was left as an island, and has since been joined to Phillip Island by a sandy tie-bar (Hills, 1940, fig. 304).

The Eastern Passage developed by the drowning of the valley of a south-flowing stream. The submarine contours of Western Port Bay, as shown on Admiralty Chart 1707, Folio 98 (1917), indicate that this stream was separated from the main drowned river system that constitutes Western Port Bay by a low interfluve, extending more or less from San Remo to Newhaven. The exposure of basalt on the short platforms west of Griffiths Point at low tide, and in the short platforms on the Phillip Island side of the Eastern Passage, indicates that the stream flowed over a

basalt-filled valley, so that there was a valley between Griffith's Point and Cape Woolamai long prior to the incidence of marine erosion. This must have speeded the marine erosion of the southern coast at its western end by concentrating wave attack at this point. A tributary to this valley, also basalt-filled, is exposed in section in the cliffs along the western coast of the Peninsula.

The tide stream through the Eastern Passage flows close to the eastern shore at The Narrows, between Newhaven and San Remo, and then swings in a wide curve over towards the Phillip Island shore. This has developed a shallow backwater on the Peninsula side of the Passage, where an extensive sandbank has been built parallel to the course of the channel. Cape Woolamai protects this sandbank from heavy seas from the south and south-west, while Griffith's Point shelters it on the south-east.

The Contrasted Coastlines.

The coastlines of the Peninsula show a striking difference in the stage of maturity to which they have attained. The northern coastline is more or less mature, while the southern one is still in its youthful stage. The major variable responsible for this difference is the different strength of wave attack to which the two coasts are exposed. The southern coast is subject to severe attack by the heavy seas that frequent Bass Strait, whereas marine erosion of the northern coast results from the much smaller waves of Western Port Bay, with its limited fetch of six to eight miles, and its shallow waters.

Both coastlines appear to be typical fault coastlines, but are actually compound coastlines, resulting from the submergence of a previously block-faulted region (Hills, 1940, p. 223). The faults are younger than the Older Volcanic basalts (Oligocene?), but pre-date the formation of the Bass River and Powlett River Plains. In other parts of South Gippsland the fault system of which these faults are members had affected Oligocene basalts, the Brown Coal series, and sands and gravels regarded as Pliocene (Herman, 1925). At Hedley, the Brown Coal, which has been downthrown by the Gelliondale Fault, is directly overlain by marine Pliocene beds (Edwards, 1939). Presumably, therefore, the faulting is of Pliocene age, which agrees with the mature character of the fault scarps, while the submergence of the down-faulted blocks took place either in the Pliocene or in the Pleistocene.

The Coastlines in Plan.

Both coastlines appear in plan as more or less straight lines, but, whereas the northern coastline shows only broad, shallow embayments, the southern coastline is markedly crenulate. The disposition of headlands and embayments along the southern

coastline is largely dependent on fold structures in the Jurassic sediments The headlands tend to develop where anticlines or domes bring beds of massive sandstone above sea level while the embayments occur where synclines or basins carry these beds down, and bring the softer overlying beds down to sea level The valleys of the Peninsula tend to develop chiefly in the softer rocks so that near the coastline the streams occur in the synclines and enter the sea at the heads of the embayments As a result along the southern coastline high cliffs occur along the anticlinal stretches of the coast with lower cliffs at the synclines This further favours the development of embayments in the synclines since the amount of material to be eroded by wave attack is proportional to the height of the cliffs

THE COASTLINES IN PROFILE

Northern Coastline—The northern coastline is fronted by a gently sloping shore platform with a gradient of about 1 in 650 the 1 fathom submarine contour being at an average distance of three quarters of a mile from the shore (Text Map) It is developed partly in Jurassic strata partly in basalts and has a sloping wave cut bench ranging in width from 50 to 100 yards (Plate VIII figs 8 10) Much of this is thickly strewn with pebbles of basalt or where the bench is cut in Jurassic of basalt mingled with grit and sandstone The pebbles are distinctly smaller at the western end of the bench where it is under the lee of Phillip Island Where it is exposed to the widest fetch across Western Part Bay from the north west it tends to be swept clean of pebbles and the edges of the Jurassic strata are exposed They show undulations in strike and in places dip to the north at angles as great as 70 degrees This section of the bench is margined on the seaward side by a reef of steeply dipping basalt formed where the basalt capping outcrops at sea level Further east the basalt outcrops in the bench itself partially covering a narrow ridge of Jurassic sediments which are exposed along the axis of the ridge

The beach behind the wave cut bench is generally only a few feet wide and along the greater part of the Jurassic outcrops quartz sand is replaced by a fine ironstone gravel Behind the beach rise cliffs which range from a nip of 1 to 2 feet high (Plate VIII fig 9) to sloping cliffs 40 feet high (Plate VIII, fig 7) and in one place vertical cliffs 40 feet high (Plate VIII fig 10) The more strongly developed cliffs occur along the basalt sections of the coast where they maintain a uniform height Two factors cause this Inland the basalt forms a flat surface sloping gently towards the sea so that as the cliffs are pushed back they tend to increase in height The resistant nature of the basalt causes streams and gullies to develop in the marginal Jurassic sediments rather than in the basalt Secondly the basalt in the cliff face is almost completely weathered to clay As a result even such

small waves as occur in Western Port can undercut the base of the cliffs and cause landslides which keep the slopes steep The face of the cliffs is honeycombed with rabbit holes and edged with talus cones of clay and a clay beach about three feet wide showing mud cracks The vertical cliffs form a stretch about 50 yards long towards the eastern end of the coastline where the weather basalt shows pronounced columnar and horizontal jointing They also face the longest fetch across Western Port and are fronted by a wave cut bench 100 yards wide free of boulders and cut in decomposed basalt

The Jurassic sediments have been eroded into more undulating forms by subaerial agencies and form cliffs of variable height with grassy and tree covered slopes (Plate VIII fig 7) Like the basalts they are subject to landslides even some distance back from the beach head Stretches of these Jurassic cliffs are no longer reached by the sea

Southern Coastline —On the southern coastline the shore platform slopes much more steeply at about 1 in 45 The 5 fathom submarine contour occurs at less than a quarter of a mile from the cliff line while the 10 fathom contour is reached at about half a mile The wave cut bench slopes even more steeply in the embayments and on the headlands is replaced by storm wave platforms (Plate VII figs 1 2 4) These storm wave platforms range in width up to 200 feet the width decreasing with increase of cliff height (Edwards 1941) They are widest on the fronts of headlands and diminish in width as they are followed into the embayments The cliffs are commonly more than 100 feet sheer in height and in places exceed 200 feet (Plate VII figs 1 2) Where the slope of the cliff top is landwards it tends to be a dip slope Parallel major joints, striking at angles up to 20 degrees from north traverse the rocks in the platforms and cliff faces The sea has cut channels along these joints dividing the storm wave platforms into isolated blocks and the sides of the headlands tend to collapse along such joint planes so that they become more or less parallel to the channels in the platforms Where the rocks overlying the platforms consist of softer shales erosion along the joint planes tends to develop caves and in one or two places small natural arches have formed where the backs of such caves have been breached The major existing caves occur east of the Punch Bowl (Text Map) and the larger of them has been breached near its back The Punch Bowl is the remains of a still larger cave whose roof has collapsed leaving a circular crater like depression about 100 feet deep with a flat floor composed of debris from the fallen roof

Rock stacks are noticeably absent except for a few miniature stacks This is a feature which is common to most parts of the Victorian coastline that are formed in Jurassic sediments

Storm ledges occur at a number of points at varying heights above the storm wave platforms where hard bands of rock overlain by softer bands are exposed to occasional wave attack. Honeycomb weathering is pronounced on the storm wave platforms and at the cliff bases. Higher up the cliffs where the rocks have been weathered and limonite has been deposited in the joint planes, the infilled joints sometimes stand in relief as intricate three dimensional patterns. At Griffith's Point a combination of strongly developed current bedding and closely spaced jointing in massive sandstone has given rise to a peculiar fluting of the cliff face where it is exposed to wave attack (Plate VII fig 6).

The recession of the cliffs is taking place more rapidly than the streams can erode their beds, but since they usually enter the sea at the heads of embayments over strata of unequal hardness, they tend to descend in a series of cascades rather than form hanging valleys in the cliff faces. Back from the cliffs rejuvenation of the streams by marine erosion has led them to cut deep gullies. At one point the development of an embayment has beheaded a small stream (Plate VII fig 4) leaving a dry valley on the headland. The stream now enters the sea by cascades in the newly formed embayment.

Sand dunes have accumulated in embayments at one or two places along the coast, but their greatest development is at Sandy Water Holes where they are still accumulating in the break in the cliff line (Plate VII fig 1). Here they are 50 feet high and enclose a small marshy lagoon which is fed by four small streams ponded behind the dunes.

Western Coastline.—The short length of coast facing the Eastern Passage is more comparable with the northern coast than the southern. At the northern (San Remo) end it consists of a broad beach fronted by sand dunes about 20 feet high. The land surface rises gradually to the south and this is reflected in the appearance of a line of cliffs which continues with only one break to Griffith's Point. Where the cliffs begin they are cut in completely decomposed basalt and are protected from further marine erosion by broad flat sandy beach which is several feet above high water mark. Southwards this protecting beach narrows and disappears and the cliffs are subject to wave attack. Basalt continues to form the cliffs for a short distance. At sea level the basalt is fresh but in the cliff face it is extremely decomposed and shows excellent concentric weathering. The sloping junction of the basalt with the Jurassic to the south, revealed in the cliff section, shows that the basalt infilled a valley in the Jurassic. Close to this junction there is a break in the cliff line due to a small stream (lateral to the basalt) entering the sea at this point. The cliffs then rise to about 20 feet in height, and slowly increase in height towards Griffith's Point. At the

same time the wave cut bench widens As on the northern and southern coasts the strata are exposed on edge in the wave cut beach and show an undulating strike They dip west at 15—25 degrees (i e seawards) and the harder beds chiefly grits project above the general level of the beach The cliffs at the southern end are fronted by sand and heavy talus deposits while at the northern end a broad sandbank or spit which is exposed at low tide extends south westwards for about a mile parallel to the tidal channel

Geology

The geology of the peninsula was first described by Walthen (1848) who noted the continuous outcrop of Carboniferous sediments from Griffith s Point to the mouth of Bourne Creek and their association with trap rocks (basalt) but was unable to establish their relationship to one another Selwyn (1854) recognized the Mesozoic or secondary Carboniferous age of the rocks and drew a section from Griffith s Point to the mouth of the Powlett River showing undulating dips of up to 20 degrees in the Carboniferous beds He also noted the presence of basalts overlying the Jurassic strata and of dykes intrusive into them The name Carboniferous was applied to the beds because of the general resemblance of the fossil flora obtained from them to the flora of the Sydney coal basin as then known and the presence in them of thin coal seams Further references to the district appear in Selwyn s reports for 1855 56 and 1868 A more detailed report accompanied by maps and sections and with a description of the lithology of the Jurassic sediments at Griffith s Point was made by Krause (1872) on behalf of the Coal Commission Quarter Sheet 67 S W showing that the peninsula consists largely of Jurassic strata overlain on the north side by Tertiary gravels and by basalts of the Older Volcanic Series was prepared by Stirling in 1892 This Quarter Sheet has been used as the basis of the Text Map In his accompanying report Stirling (1893) gives details of the exploration for coal near Kilcunda and a description of the Jurassic rocks and their flora together with a reprint of some of Krause s data Other references to the coal seams are to be found in the reports of Mackenzie (1873) Cowan (1875), and Murray (1884 1887), while descriptions of the fossil leaf remains found on the peninsula are given in papers by Stirling (1900) Seward (1904), and Chapman (1908 1909)

The Jurassic Rocks

Structure—Two distinct elements of structure exist in the Jurassic sediments of South Gippsland —(1) a regional tilt in each of the major fault blocks and (2) folding due, probably, to differential compaction

Observations at San Remo and elsewhere in South Gippsland indicate that each of the major fault blocks in South Gippsland was tilted during the faulting of the region so that it shows a prevailing dip of 5 degrees to 25 degrees in a direction more or less at right angles to one or other of the boundary faults The effect of this tilting is apparent in the streams Broad rapids sloping with the dip like the Tarra Falls develop on the back slope streams while narrow rapids across the edges of strata and waterfalls like Agnes Falls characterize the scarp streams In some of the tilted blocks the angle of tilt steepens in the vicinity of the boundary fault and may become more or less vertical as a result of monoclinal warping along the line of fault This has been noted along the Yarragon escarpment (Herman 1925) along the Bass escarpment (Ferguson 1909) and appears to be the case along the extension of the Bass escarpment that forms the northern coastline of the San Remo Peninsula where the Jurassic rocks and the overlying Tertiary basalts are found dipping to the north at angles ranging up to 70 degrees along the shore platform and in a bore put down a short distance back from the shore (Krause 1872) Modifications of the regional dip have also been caused by lesser faulting within the fault blocks Such faults are not readily detected except in mine workings and cliff sections Sections through the Wonthaggi coalfield however show that numerous east west faults more or less parallel to the major faults of the region have broken the Wonthaggi block into a number of small steps descending to the north with sometimes a tilting of the minor blocks and frequently a warping of the beds into semi saucer shaped sags (Hunter and Ower 1914) These half basins face south and the amount of sag dies away to east and west as the faults die out in these directions Occasional exposures along the southern coast of the Peninsula show a local steepening of dip due to drag along a small fault Examples can be seen between Kilcunda and Hoddinot s coal shaft and on the point west of the Sandy Water Holes

In addition as Selwyn (1854) noted the sediments are gently folded Stirling (1897) in his report on the adjacent Quarter Sheet 34 S E referred to such folding as an irregular puckering up of the strata rather than regular corrugations formed by anticlinal and synclinal curves The folds take the form of small often irregularly shaped domes and basins of shallow closure with dips of 5 degrees to 20 degrees and diameters rarely exceeding one mile and generally much smaller Such folding is suggested in many parts of the South Gippsland Highlands by the irregular and sometimes more or less radial arrangement of the dips about certain foci Where sections have been cut through a series of these domes and basins as along the coastlines of the San Remo Peninsula and near Cape Paterson they appear as alternating anticlines and synclines sometimes apparently pitching into the cliff sometimes towards the sea As many as nine

folds to the mile are developed in places along the southern coast of the San Remo Peninsula, while in the vicinity of Cape Paterson they average three to the mile. The apparent pitch may be maintained in one direction for a considerable stretch of the coast, or may be reversed fairly frequently, according to the disposition of successive domes and basins with respect to the cliff sections. Frequently the pitch is in the direction of the regional tilt of the fault block. Thus it is generally to the north, at 10 degrees to 15 degrees along the southern coast of the Peninsula, where the fault block is tilted at about 5 degrees to the north. Near Cape Paterson it is generally to the south at about 20 degrees. Where the apparent pitch is opposed to the tilt of the fault block it is distinctly less steep than where it combines with the tilt. Thus, along the San Remo Peninsula, such apparent south pitch as occurs is of the order of 3 degrees

Where exposures are not adequate, it may prove impossible to distinguish folds of this type from the "semi-saucer-shaped" sags that accompany the minor faulting on the Wonthaggi fault block. On the Peninsula, however, the edges of the beds are exposed both in north-south and east-west sections. Along the northern and southern shore platforms the beds show an apparent east-west strike with undulations (sinuosity) corresponding to the fold undulations in the cliff sections. Along the western shore platform facing the Eastern Passage, the beds show an apparent north-south strike, with comparable undulations and a variable westerly dip

This folding developed prior to the faulting and tilting of the region, since the Tertiary basalts infill valleys that cut through the folds. The irregular and minor character of the folding suggests that it is due to differential compaction rather than to earth movements.

Jointing.—The strata are traversed by numerous major joints, frequently in parallel sets. They can be seen only in the cliff sections and on the storm-wave platforms of the southern coast, where they trend more or less north-south, and continue through thicknesses of beds greater than 100 feet, without any deviation of the joint plane in its passage from one bed to another. Presumably these joints developed during the differential compaction of the beds. Minor joint planes are prominently developed in the massive sandstones, and produce more or less rectangular patterns on the smooth surfaces of some of the storm-wave platforms (Plate VII., fig. 5).

Thickness.—The greatest thickness of Jurassic sediments exposed in the Peninsula is along the southern coast, and here the close spacing of the folds, combined with their low dips, limits the thickness of rocks exposed in the cliff sections to about 300 feet. The total thickness is considerably greater, however,

since a bore put down at sea-level near Griffith's Point penetrated 857 feet without passing out of Jurassic rocks (Selwyn, 1868, p. 12). The thickness of exposed rocks increases towards the north-east in the Bass Ranges, and the thickness in depth probably grows greater also, since a bore near the Kilcunda Coal Mine was sunk to a depth of 1,158 feet in Jurassic sediments without passing out of them (Stirling, 1892).

Lithology.—As noted by Selwyn (1834), Krause (1872), Stirling (1892), and Ferguson (1909), the Jurassic rocks consist of sandstones, shales, coal seams, and coalaceous beds, conglomerates, and grits.

Sandstones.—The sandstones vary somewhat in character. One variety, which occurs at the base of the cliffs, consists of a massive green rock, over 50 feet thick. It commonly shows pronounced current bedding, as at Griffith's Point, and prominent vertical jointing in two directions more or less at right angles to the bedding planes, so that it breaks away in large rectangular blocks. Close to Griffith's Point this stone was quarried for building purposes as early as 1850 (Selwyn and Ulrich, 1866), and shipped to Melbourne.

Thin sections show that it is highly felspathic. The felspar is present largely as irregular-shaped grains of plagioclase, which is optically positive, with an extinction angle in the symmetrical zone of 10 degrees to 20 degrees, indicating that it is basic oligoclase or andesine. In addition, there are much less numerous grains of cloudy orthoclase, perthite, and microcline. Very occasionally the felspar is graphically intergrown with quartz Quartz occurs abundantly, but only occasionally as well-rounded grains. Most of the quartz grains are angular, some are composite, and some show well-marked embayment, such as one observes in quartz phenocrysts in acid lava flows Flakes of bleached biotite are not uncommon, and occasional grains of enstatite are also present. Other minerals noted are epidote, chlorite and zircon. In addition to the mineral grains, there are many rounded fragments of igneous rock, of about the same general size Some of these are glassy, others are microporphyritic. They are of a uniform type, however, consisting of a fine to glassy ground mass studded with numerous microlites of plagioclase with almost straight extinction. The microlites frequently show flow alignment. The rock is presumably a glassy andesite, or an oligoclase basalt.

The uniform size of the grains points to sorting during deposition, but their irregular shapes indicate that they did not undergo prolonged water erosion prior to deposition. They are now commonly cemented together by narrow rims of zeolitic material which occasionally forms spherulitic growths. The materials composing the sandstone are definitely of igneous origin, and in

part are derived from lava flows Some of the material is almost certainly derived from the nearby Woolamai granite because higher up in the sequence thin beds of similar sandstone up to 1 foot in thickness are intercalated with beds of coarse grit up to several feet thick in which the component minerals are chiefly coarse allotriomorphic and often composite grains of quartz and orthoclase which can only have come from the Woolamai granite

The uniform sizing of the grains combined with their non waterworn character suggests that they may have been deposited as volcanic tuff

Frequently these massive sandstones carry oval or spherical masses up to 2 feet in diameter of sandstone of apparently identical composition and only slightly harder consistency These cannon balls weather out on the surface and give the sandstone a knobby appearance They are characteristic of the massive green sandstones wherever they occur throughout the Jurassic areas They occur within the beds and not along the bedding planes so that they appear to be syngenetic concretions although they show no concentric structures when broken open Elsewhere the sandstones carry boulders of foreign origin These consist of granite aplite reef quartz hornfels sandstone grey and black shales and junks of calcified wood Ferguson (1909) records the occurrence of two boulders of granite three feet in diameter in sandstone near Kilcunda, and suggests that they are glacial erratics and Hunter and Ower (1914) record a pebble of an acid dyke rock from the roof of No 5 workings in the State Coal Mine Wonthaggi The sedimentary boulders in part at least are derived from Upper Ordovician strata since Hall (1904) found Upper Ordovician graptolites in some of the black shale or slate pebbles The granite pebbles can be matched with the Cape Woolamai granite The boulders are never sufficiently numerous however for the rocks to be termed conglomerate and tend to become fewer in number east of Griffith's Point

Lesser thicknesses of grey friable sandstone occur at higher levels in the cliff sections These sometimes show numerous bedding planes less than an inch apart sometimes with coaly matter forming a film along the bedding planes Sometimes they are very closely jointed Mineralogically they are similar to the massive sandstones

Conglomerates —These outcrop as beds rarely more than two or three feet thick intercalated with grits and sandstones on the shore platform west of Griffith's Point where they are exposed at low tide Stirling (1892) mapped about five such beds in a distance of a quarter of a mile The boulders in the conglomerates are well rounded and up to nine inches in diameter, though generally smaller They consist of Woolamai granite,

aplite, reef quartz, hornfels, and other metamorphosed sediments, shale and black slates They grade laterally into grits and felspathic sandstones with scattered boulders of similar character

Some of the beds consist largely of small flat pebbles of soft grey shale in a sandy matrix, and beds of this sort occur sporadically as far east as Kilcunda and Cape Paterson

Both Stirling (1892) and Ferguson (1909) considered that these conglomerates 'comprise the basal members of the south-west margin of the Gippsland carbonaceous deposits," but as Hunter and Ower (1914) have pointed out this can scarcely be so, because these conglomerate beds overlie the massive sandstones at Griffith's Point where a bore penetrated 850 feet further down in Jurassic strata With the grits however they undoubtedly mark a marginal facies in the Jurassic since both are derived from the Woolamai granite and the rocks of its contact aureole, and die away eastwards as the distance from the granite stock becomes greater At the time of their deposition the Woolamai granite and the adjacent Palaeozoic sediments must have formed either an island or a shoreline of the Jurassic lake

Grits —Coarse to fine grits are prominently developed along the shore platform facing the Eastern Passage, from Griffith's Point as far as the basalt contact, and they recur from under the basalt in the most westerly outcrop of Jurassic rocks along the northern coast The bulk of the coarse material consists of irregular grains of quartz 2 to 5 m m across, and fragments of large orthoclase crystals of similar size In addition small flat pebbles of shale and sandstone and fragments of more or less calcified wood are common The beds range up to ten feet in thickness but are lens like and rapidly grade into sandstones They frequently alternate with beds of sandstone a foot or less thick when the bases of the successive grit beds are marked by a film of carbonaceous matter and sporadic junks of coalified or calcified wood

Shales —Shales occur as thin black and grey bands sometimes associated with thin coal seams chiefly along the eastern half of the south coast The individual beds are often only one quarter of an inch thick, but the aggregate thickness may be five to ten feet The shales are often overlain by beds of friable blue-grey sandstone which is characterized by close and slightly irregular rectangular jointing These two types of rock alternate with bands of harder green sandstone in the cliff faces

Coal Seams —Coaly matter occurs as "cakes," films and discontinuous beds an inch or more thick accompanied by woody fragments, along the western end of the southern coast The coaly seams generally occur associated with shaly conglomerates, just above the massive green sandstones, and at the base of grit beds overlying such sandstones Such coal beds cannot be

traced for more than 20 to 30 yards in section Further eastwards true coal seams are found outcropping, and just west of Sandy Water Holes six such seams occur in the cliff face in a thickness of 50 feet The thickest seam is two feet thick, and has been encountered in a shaft 100 feet back from the cliff top A further coal seam outcrops in the cliff face and the bed of the creek just east of Black Head This seam was 3 ft 6 in wide where it outcropped in the creek bed but when followed inland developed a parting of clay 1 foot thick It was cut at a depth of 33 feet from the surface in a shaft sunk 100 feet north west of the outcrop This seam has been opened up and is being worked at present on a small scale Two more seams of workable thickness 2 ft 3 in to 2 ft 6 in dipping at 8 degrees N L occur to the north west of the Kilcunda Railway Station and are being mined The coal is finely banded and is a fair quality bituminous variety No other coal seams of commercial value have been found on the Peninsula although a certain amount of boring has been done near San Remo and Griffith's Point The thickest seams encountered in these bores did not exceed twelve inches

Conditions of Deposition —The nature of the sediments and the prominent current bedding in the sandstones make it clear that deposition took place in relatively shallow water subject to storms or to heavy rains The fact that such sediments are found more than 850 feet above the base of the Jurassic points to steady subsidence within the area during deposition This thickness of sediments below present sea level and the height to which the Woolamai granite projects above present sea level point to the existence close by of a steeply sloping shoreline and the occurrence of seams and films of coalified matter at the base of the grit beds suggests that both the vegetal matter and the material forming the grits was swept down from these steep slopes during periods of heavy rainfall

The mixture of volcanic matter with granite derived matter in the sandstones suggests that tuffaceous material was constantly falling into the shallow lake throughout the period of deposition of the Jurassic sediments

Tertiary Basalts and Dykes

Basalts of the Older Volcanic Series cover much of the northern part of the Peninsula (Fig 1) and outcrop at intervals to the north at Stony Point Cobb's Bluff Cornella and Queensferry At Cornella and Queensferry they are overlain by "Red Beds"

Several types of olivine-basalt are present They include titanaugite basalts of the Moorooduc type, glassy basalts of the Keilor type, and olivine basalts of the Flinders type (Edwards, 1939)

A number of basaltic dykes with a general strike west of north, occur in the Jurassic rocks north of Kilcunda and along the shoreline (Edwards, 1934)

Three such dykes outcrop in the cliffs and shore platform along the southern coast of the Peninsula proper Two of them are rapidly chilled olivine basalts The third which occurs at the head of an embayment about one mile east of Griffith's Point is eight feet wide with well defined chilled margins about two feet thick at either contact and distinctly coarser central part, which is more weathered than the margins A thin section of fresh material shows it to be a coarse grained olivine basalt of the Flinders type in which the olivine in altering to serpentine has given rise to flakes of deep brown biotite

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Explanation of Plates.

PLATE VII

FIG 1—The southern coast of the San Remo Peninsula looking eastwards from near the Sandy Water Holes towards Black Head in the distance The dip of the Jurassic strata is inland at Black Head and seaward at the headland in the middle distance The headlands are fronted by storm wave platforms The Sandy Water Holes lie behind the sand dunes in the foreground

FIG 2—The southern coast of the San Remo Peninsula looking westwards from Black Head

FIG 3—The profile of the Cape Woolamai granite stock on Phillip Island showing the northward slope of the granite surface The view is taken from a storm wave ledge at Griffith's Point

FIG 4—A beheaded valley on the headland west of Houldinct's coal seam Vertical major joints can be seen in the cliff face and the storm wave platform

FIG 5—Jointing in the smooth surface of a storm wave platform cut in massive sandstone at Griffith's Point

FIG 6—Effect of wave erosion on vertically jointed current bedded sandstone at Griffith's Point

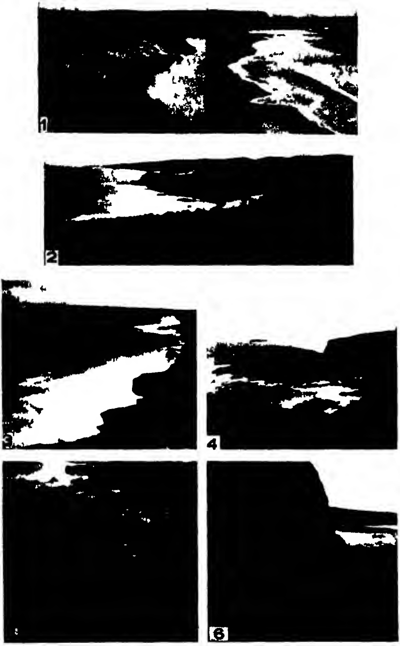
PLATE VIII

FIG 7—A stretch of northern coast of the San Remo Peninsula, cut in Jurassic sediments looking west at mid tide

FIG 8—A stretch of the northern coast of the Peninsula looking west at low tide The headland in the near background consists of basalt Phillip Island (Newhaven) lies in the background

FIG 9—Gently sloping cliff covered by vegetation and fronted by a nip Northern coast of San Remo Peninsula

FIG 10—Vertical cliffs in decomposed columnar basalt, fronted by a broad wave-cut bench eroded in fresher basalt on the northern coast of the Peninsula The grassy cliff slopes on the left are formed on Jurassic sediments, and are subject to landslides The steeper cliffs on the right are cut in basalt decomposed to clay



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[PROC ROY SOC VICTORIA, 54 (N S), PT I, 1942]

ART V—*The Physiography of the Koo-wee-rup Swamp.*

By E S HILLS, D Sc

[Read 10th July, 1941 issued separately 15th April 1942]

Introduction.

The Koo-wee rup Swamp or Great Swamp as it was termed on early maps, is situated in the low lying alluvial terrain between the foot hills of the Eastern Highlands and the head of Western Port Bay Reclamation of the Swamp was commenced in 1885, and no detailed account of its original condition is extant Traverse notes of surveyors and the meagre information available from other sources indicate that the central part of the swamp was covered with water in which grew rushes and reeds (probably *Phragmites communis* and species of *Scirpus*), and that the marginal land was more complex, with tea-tree (*Melaleuca ericifolia*) in damp depressions between low sand ridges and water channels in places East (1935) remarks that The soil of the swamp itself consisted of fibrous peat 6 to 10 feet deep water-logged for the most part an ideal haven for wild fowl, deer and wombats" Since peat was formed over the whole of the central portion of the swampland, it is clear that anaerobic conditions existed there, and as mentioned above, it is known that there were areas of standing water in which grew the *Phragmites* and other plants of which the peat is composed (see Goudie, 1942) Yet the swamp has a fall throughout its length, ranging from 3 feet per mile in the lower reaches of the main drain to 10 feet per mile near Bunyip Hence there can have been no continuous standing water-body of the dimensions of the swamp, and it is suggested that the central portions consisted of relatively small lake-like cells, separated by dense growths of rushes and reeds which acted as slowly permeable barriers to the flow of surface waters, while the bottom water moved even more slowly through a spongy mass of peaty soil Where sand ridges rose above the level of the swamp (as they did in places, being used as natural routes into it) they aided in the impedence of drainage The area of deep peat (Goudie, 1942, Plate X) lies between the sandy complex of the Bayles district (parts of which were above swamp level), the alluvial flats of the Yallock Creek (which likewise were outside and probably at a higher level than the swamp), and the alluvial fans of the Lang Lang River and King Parrot Creek on the east Here drainage towards the coast was particularly slow, and a large area of standing water may possibly have existed The waters of the swamp were derived mainly from the Bunyip River, the defined channel of which could formerly be followed for about 2½ miles south of the Bunyip township, before it became

dissipated within the swamp To day the Bunyip waters are carried by the main drain which is scouring deeply in the north and aggrading in the south around Koo wee rup (see East 1935 for further details of the reclamation scheme)

Shrinkage of the peat deposits of the swamp has resulted from drainage oxidation of carbonaceous material wind erosion consolidation by trampling during farm work and in places from burning so that considerable subsidence has taken place since the swamp was reclaimed The extent and magnitude of this are indicated on the map (fig 1) and it may be seen by reference to the soil map prepared by Goudie that significant subsidence is restricted to the actual paludal area in which peat occurs The maximum amount of subsidence about 8 feet took place where the peat deposits were deepest and no subsidence can be detected on non peaty areas such as the alluvial flats bordering the Yallock Creek East (1935) has pointed out that the underlying clays did not shrink appreciably on draining

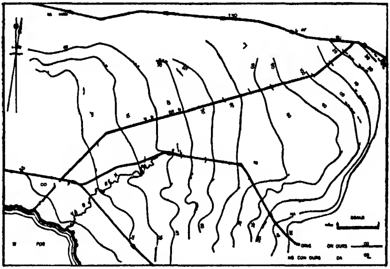

FIG 1—Topographic map of the Koo wee rup Swamp from data supplied by the State Rivers and Water Supply Commission Existing contours are shown where they differ from the original contours as a result of subsidence

Topography

The alluvial terrain in which the Koo wee rup Swamp is situated has the topographic form of a half basin which may be referred to as the Koo wee rup Basin This is bounded on the east by the Heath Hill Scarp which trends N N E from Grantville to Longwarry and marks the western edge of the South Gippsland Highlands From Heath Hill northwards the scarp is composed of Older Volcanic basic lavas but south from Heath Hill these are covered by late Tertiary sands clays, and gravels,

which also extend westwards from the scarp towards Lang Lang and reach the coast at the Red Bluff Lang Lang Beach The northern rim of the basin is formed by the foothills of the Eastern Highlands long spurs from which extend southwards between the broad alluviated valleys of south flowing streams On the west the plain of the Cranbourne district composed of Tertiary sands gravels and Older Volcanic rocks with isolated inliers of Silurian bedrock passes gradually beneath the alluvial deposits of the basin (see fig 5) The broad valleys of insignificant streams such as Clyde Creek carry tongues of alluvium into the plain and outlying hillocks of Tertiary sands are in places surrounded by alluvial deposits In the south these deposits merge into the tidal mudflats at the head of Western Port Bay

The Coast

In the neighbourhood of Quail Island the sandy plain of the Cranbourne district reaches the sea and in this district long tidal inlets known as creeks extend inland between low hills composed of Tertiary sands and sandy clays Salt marshes and mangrove swamps border the mud bottomed tidal channels The range of spring tides in Western Port is 8 feet with low water mark 2 feet below low water mark Hobson s Bay and the salt marshes lie at or slightly below storm tide level Cliffs cut in the soft Tertiary sediments are suffering rapid erosion by tidal scour This stretch of coastline it is clear originated as a result of the submergence of the edge of the Cranbourne plain which adjoins the Koo wee rup Basin on the west The creeks are drowned valleys in which natural reclamation by siltation in mangrove swamps and salt marshes is now in progress

The long branching tidal channels known as The Inlets lying to the east of Tooradin are however of a different nature They traverse gently sloping alluvial flats that are with the exception of one or two small areas below storm tide level and were before the building of levees periodically inundated by the sea In plan the Inlets show a dendritic pattern of branching channels each representing a self contained drainage unit which is long compared with its breadth and they present a remarkable similarity in form to the rill marks that develop on sloping surfaces of water saturated sand or mud such as may be seen on beaches at low tide (fig 2) Each rill is a miniature dendritic drainage system of the order of a foot or a yard in length the main channels of some examples being meandrine and of others fairly straight (see Chamberlin and Salisbury 1905 figs 325 326)

The physiographic setting of the Inlets is directly comparable with the conditions under which rill mark is developed They arise at the edge of and serve to drain the formerly water-saturated alluvium of the Dalmore Swamp and the south westerly trending terminal ' arm " of the Koo wee rup Swamp The channels were fed by seepage from this saturated alluvium and

it is suggested that they have become permanently fixed in position as a result of tidal scour. At present, owing possibly to the acceleration of siltation consequent upon the carrying of large amounts of detritus into the Bay by the drains, the Inlets are silting up. Sawtell's Creek differs from the Inlets in its remarkably meandrine course. Aerial photographs (Plate IX, fig 2) show that the meanders have undergone normal shifting as with river meanders, but the head of the main creek is in the south western part of the Dalmore Swamp, and the defined channel does not carry on through the Swamp to link up with a normal stream course in the north. It is therefore clear that Sawtell's Creek, though differing from the Inlets in its strongly meandrine course, is like them merely a seepage channel fed by drainage from a swamp. It may be noted that the pattern exhibited by the channels in the tidal flats at the head of Western Port Bay closely resembles that of the Inlets and of Sawtell's Creek (fig 2). At first sight this might suggest that the Inlets are upraised tidal scour channels, but since they are still subject to tidal inundation this explanation is inadequate.

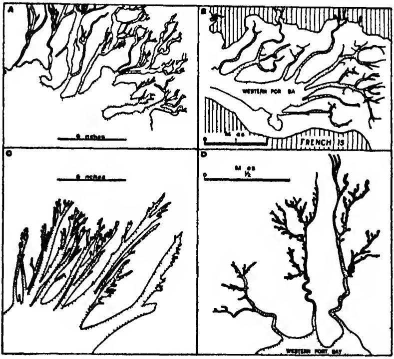

FIG 2 — Diagrams to show the analogy in plan of rill mark (A and C), tidal channels in mud flats at the head of Western Port Bay (B) and the Inlets east of Tooradin (D)

A and C after Chamberlin and Salisbury (1905), scale approximate only; B after the Admiralty Chart; D from a survey by the State Rivers and Water Supply Commission

East of the Inlets the coastline is not indented as it is to the west The alluvial flats bordering on the Yallock Creek for example slope gently towards the sea and terminate in a low cliff about 3 feet high over which storm tides flood The cliff and the tidal flats off shore at this point have been excavated in the fluviatile flood plain deposits chiefly dark clay with dispersed grit particles laid down by the Yallock Creek (fig 3) This creek is the natural outlet to the eastern portion of the Koo wee rup Swamp but it differs from the Inlets in that it does not itself traverse swamp land

Fig 3—Mouth of Yallock Creek at low tide, showing the low cliff and shore platform cut in alluvium

At the Red Bluff on Lang Lang Beach Tertiary sands grits and clays reappear in the cliff sections and the physical features of the coast change The seaward face of the Red Bluff is still undergoing marine erosion but to the north and south the coastline is prograding Stockyard Point on the south is a broad complex of sand ridges with intervening swales built up just above normal high tide level but still subject to marine incursions during storms The ridges are beach ridges aeolian sand drift being subordinate because of the presence of vegetation and the numerous swampy swales When submergence first occurred a low marine cliff was formed in the soft Tertiary sands and sandy clays of the Red Bluff ridge but as a result of the formation of successive sand ridges which were probably initiated as barrier beaches trending north and south from the headland this cliff has been removed from the influence of marine erosion

and is now flanked by an apron of small alluvial cones and fans which merge into the lagoonal deposits formed behind the sand ridges at high tide level

In the Grantville district submergence brought the sea into contact with the alluvial cones and fans derived from the Heath Hill Scarp Low cliffs about 6 8 feet high were cut in the outer edges of the fans and as a result the streams that formerly migrated freely over them in the course of aggradation were rejuvenated and are now incised in fixed channels on the fans This effect is of considerable importance in the interpretation of changes of sea level relative to the land as judged by the condition of streams for it leads to the unexpected result that under certain circumstances rejuvenation may result from submergence After the above events had gone on normal progradation at storm tide level took place especially in the bay heads and thus the coast from Grantville northwards is now fringed with a low lying ridge and swale complex behind which is the initial coastline formed on submergence (fig 4)

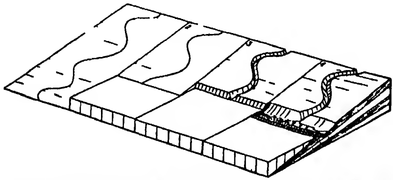

FIG 4—Block diagram to illustrate the sequence of events in the evolution of the coast near Grantville (1) Stream depositing alluvial fan before submergence (2) submergence (3) cliffing and rejuvenation of the stream (4) progradation and wasting of the former marine cliff

It will now be clear that there is no evidence in the region of coastline investigated for any Recent emergence such as has been recorded in Port Phillip Bay (Hills 1940) The last major event in the physiographic history of the coast line at the head of Western Port Bay was submergence While it is tempting to regard this as due to the post Glacial eustatic rise of sea level advocated by Daly there is little evidence to support this idea

The submergence of the flood plain deposits of the Yallock Creek, and of the alluvial fans at Grantville suggests rather that the marine incursion was a local phenomenon of Recent date, caused by tectonic depression of the Koo wee rup Basin This conclusion, of course does not in any way affect the conception

that there very probably was a previous post-Glacial eustatic rise of sea level. The important question of whether submergence is still in progress is also difficult to decide. All that can be said is that north of Grantville tea tree grows to the water's edge where it is dying, probably as a result of the immersion of its roots in salt water. Peaty clays laid down after the original submergence at this point are now exposed on the beach between low and high water mark, and there is therefore a suggestion that submergence may still be in progress. The evidence available is, however, not conclusive, since the level at which these deposits formed is not known with certainty.

The Koo-wee-rup Basin—Geological History

The geological history of the Koo-wee-rup Basin during Cainozoic times may be commenced with the development of the pre-Older Volcanic terrain. This land surface was formed on Silurian sedimentary rocks, Palaeozoic granites and Jurassic sedimentary rocks, and appears to have been of little diversified relief, though well-defined river valleys existed. In pre-Batesfordian (Oligocene?) times impure brown coals, sands and clays were laid down, and the Older Volcanic lava flows were extruded. During the Miocene a marine incursion recorded by the presence of Lepidocycline limestones overlying lignites in bores at Lyabb indicates a partial submergence of the area beneath the sea (Bore Records 1919-22 (1929), p. 28). At Cardinia, too, Lepidocyclinae have recently been obtained at about 150 feet below the surface in a bore (Allotment 4, Section A1, in the Parish of Pakenham). Mr. W. J. Parr has kindly supplied the following information on this discovery:—

Description of Material.—Light-coloured foraminiferal sand (in parts cemented) with frequent rounded grains of quartz. In addition to the foraminifera, there are large specimens of a calcareous alga, *Lithothamnium* sp. (the largest with a diameter of 1½ inches) and worn bryozoans.

List of Foraminifera.

Gypsina globulus (Reuss).

Gypsina howchini Chapman.

Amphistegina sp. aff. *hauerina* d'Orbigny.

Lepidocyclina (*Nephrolepidina*) *hamiltonensis* Chapman and Crespin.

Remarks.—The foraminifera, particularly *L.* (*N.*) *hamiltonensis* and *Gypsina howchini*, fix the age of the bed as Batesfordian. The same species occur at Flinders and in the Hamilton district (Clifton Bank, the red limestone on the Grange Burn, and in the Mines Department bore). The specimens are very well developed. A good many are worn, this evidence of rolling and

the presence of the rounded sand grains indicate that the deposit was laid down close to the shore line." The foraminiferal sand is underlain by a decomposed Older Volcanic basalt

This marine incursion was followed by the deposition of some 300 feet of late Cainozoic sands, gravels, and clays of continental facies, which covered a wider area than the present Koo-wee-rup basin, since they extend on to the Heath Hill fault block in the Nyora district and also over parts of the Mornington Peninsula, especially in the north. Although the provenance of these deposits has not been determined, it is most probable that they were derived from highlands in the north, this indicating a probable tilting—the highlands rising and the region to the south subsiding. After the deposition of these continental sediments, faulting and warping occurred, probably in Middle and Upper Pliocene times, the block to the east of the Heath Hill Scarp being relatively uplifted, and the Koo-wee-rup Basin depressed. As will be clear from the geological cross-section (fig 5), the western block is tilted, inclining downwards towards the east.

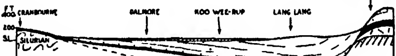

FIG. 5 Sketch geological cross section from Cranbourne to the Heath Hill Scarp, through Koo wee rup

The Heath Hill Fault dies away to the north of Picnic Point on the main Gippsland road, and also to the south, beyond Grantville, its maximum throw being in the neighbourhood of Heath Hill. The downthrown block to the west, while exhibiting an easterly tilt, is also warped about an E.–W. axis, so that the Older Volcanic rocks that pass beneath Tertiary sands in the north, reappear in the south of French Island. The existence of a westerly salient projecting from the Heath Hill scarp towards Lang Lang and the Red Bluff suggests, too, that subsidiary east-west warp axes or faults may have been concerned in the elevation of these Older rocks in the south, but to establish the position of these axes boring would be necessary. It is, however, clear that the bedrock surface beneath the Koo-wee-rup Basin is itself a true tectonic basin, in which Cainozoic sedimentation has gone on from pre-Older Volcanic times until the present day.

After the completion of the differential movements that determined the major features of the existing topography, most of the Tertiary sands and gravels were eroded off the higher land The stripping of these deposits from the southern edge of the Eastern Highlands has revealed the formerly buried terrain of Older Volcanic lava residuals and bedrock ridges, which pass below the Tertiary sedimentary rocks of the basin The Cranbourne sand and its equivalents in other localities (see Holmes, Leeper and Nicholls 1940) which form a covering sheet over the underlying more argillaceous continental Tertiary deposits, is a dominantly fluviatile deposit very probably derived in large measure from uplifted portions of the Older Tertiary sediments On the sandy plains brought into existence during this period of erosion and deposition aeolian activity gave rise to sand hills in places as for example on the Tooradin Road near Fisher's Road

As the penultimate stage in the evolution of the Koo wee rup Basin before the advance of the sea may be pictured the deposition of broad low alluvial fans by streams debouching from the marginal higher land on the north west, and east and also from the site of French Island, which had not yet been separated from the mainland

The evidence above advanced from the study of the present shoreline indicates that the swamp deposits had probably already been laid down when the marine incursion took place and they continued to form until the swamp was reclaimed

Origin of the Koo-wee-rup Swamp.

In relationship to the origin of the Koo wee rup Swamp, several points have to be elucidated Firstly it should be noted that there was only one episode of peat formation, which persisted at Koo-wee rup up till the time of reclamation In the Dalmore Swamp however the period of peat formation was followed by the deposition of black clay As the deposits of these two swamps are continuous, it is clear that the cessation of peat deposition at Dalmore was brought about by some local physiographic change that did not affect the Koo-wee rup district This suggests that a drainage modification affected the streams feeding the Dalmore Swamp, and there is evidence that a change of this nature did occur

Aerial photographs reveal in the St Germain's district the former existence of stream courses, extending from near the eastern end of O'Connor's Road south-easterly to St Germain's and "Carajon" (see Military Survey, Cranbourne Sheet) These old stream courses are quite independent of the Cardinia Creek, as they lead back to the low divide near "Gwenhurst", at the head of the creek that flows north-westerly from there to the Hallam Valley flats The meanders have larger radii of curvature than those of the present Cardinia Creek, and it is quite certain

that a larger creek than this formerly flowed over the St Germain s country towards the Dalmore Swamp (Plate X, fig 1)

This stream has now vanished, probably as a result of the reversal of its upper regions by depression of the country to the north west of Gwenhurst The small creek now flowing north westerly from that point has an extremely low gradient and its outlet to the Eumemmering Creek is an artificial drain only Thus the indications are that the Dalmore Swamp formerly received considerably larger supplies of water than it now does It is suggested that during this period the peat accumulated then with the sudden reduction of water supply the conditions became unsuitable for peat formation swamp tea tree invaded the area, and the superficial black clay was deposited The tea tree persisted until the district was cleared and drained its presence indicating that the permanently anaerobic conditions with a continual cover of surface water such as must have existed when the peat formed had given place to a somewhat drier but still swampy environment

It may be concluded from the history of the Dalmore Swamp as well as from the recorded facts that tea tree grew on the fringe of the Koo wee rup Swamp while the peat deposits formed in standing water in the central parts that the initiation of peat formation followed an increase in the supply of water to the site of the swamp This probably resulted from a climatic change involving either an increase in precipitation or a decrease in evaporation especially as regards the summer months Whichever factor was dominant and of course both may have changed it appears very probable that an increase in the ratio of precipitation to evaporation was the prime cause of the initiation of a peat forming environment

In any discussion of possible changes in the conditions of the streams entering the basin the sand and gravel deposits in the sandy complexes (see soil map by Goudie) must be considered Although the areas so mapped by Goudie contain most of the sand and gravel deposits associated with swamp there are also scattered sand ridges in those parts mapped as the normal peaty phase of the swamp and if the reports of local residents are reliable certain of these ridges were used as routes along which cattle could be driven into the swamp to forage on the sedges It is therefore clear that some at least of these ridges were not related to river courses then in existence but must be older than the adjacent swamp deposits In some places indeed peat overlies sand ridges and the latter are necessarily older Furthermore the sandy complex near Bayles is not connected at the surface with the northern sandy complex although sand ridges continue from it parallel to the main drain for some miles towards Bunyip Any modern stream in order to deposit this

sand, would have had to "ferry" it across the swamp, an impossible condition in view of the fact that some of the gravels near Bayles contain pebbles ½ inch in length

It therefore appears that the deposition of the Bayles sandy complex ante-dates the formation of the swamp The northern complex, too, is not connected with the course of the Bunyip River by surface sand deposits Along its northern edge is a strip of peaty soil that was formed in a local swamp fed by the streams to the west of the Bunyip River and hence is probably younger than the sandy complex that blocked these streams in the south

The available information therefore indicates that the bulk of the sandy complexes was laid down before the swamps were formed and they very probably represent the higher portions of an old alluvial fan deposited by the Bunyip River As the stream wandered over its growing fan particular strips in which it held its course for a relatively protracted period would be built up and between these shallow depressions with finer grades of alluvial deposits would remain During the formation of the sandy complexes the Bunyip River was actively aggrading and was supplied with coarse detritus especially from the granitic terrain in its headwater region

These conditions suggest that the climate at the time was more arid than at present With a lower P/E ratio much country that is now completely vegetated may have been relatively barren and the granites would have weathered by crumbling into their component mineral grains The Bunyip River would have had a smaller total flow than it has to-day but during floods large amounts of detritus would have been moved from the hills and deposited in the aggrading reaches of the stream in the Koo wee rup Basin At the same time the Lang Lang River and other streams entering the basin would have experienced similar conditions Sand ridges now vegetated that were deposited by the Cardinia Creek extend for at least 3 miles beyond the termination of the natural channel of the stream but the present stream is capable of carrying sand thus far and even further since it has been confined in an artificial channel

The Bunyip River too is capable of transporting sand of the same coarseness as that in the sandy complexes out into Western Port Bay Hence the (apparent) cessation of formation of the sandy alluvial fans that attended the initiation of the swamps involved more probably an increase in precipitation than a decrease As a result vegetation fixed much of the sand and gravel of the fans the catchment became more densely vegetated and the supply of sand and gravel decreased The immediate run off from the hills was reduced but the delayed run off increased, which aided in making formerly intermittent streams permanent, an important factor in the alimentation of the swamp

As these changes progressed, it is suggested that swamp tea-tree first established itself on the lower and wetter parts of the alluvial fan. With the establishment of a permanent water supply to these parts, however, the tea-tree was killed and its place taken by reeds and rushes, growing in the lake-like cells referred to above. Thus were finally established the anaerobic conditions under which the peat accumulated.

As Twenhofel points out (1926, p 576), "The development of peat in swamps checks the drainage of an already poorly-drained surface and also hinders evaporation. The level of the water rises and the swamp expands laterally. This expansion may result in the entire surface becoming swampy."

During floods, the fringing tea-tree acted as a barrier to the water, through which it could penetrate only slowly. Through any gaps in the tea-tree barrier, currents probably carried a little sand and gravel into the swamp, so that, with changing conditions in the barrier, the whole of the swamp may have at different times received small amounts of such coarse detrital material. This accounts for the presence of sand and gravel particles dispersed throughout the clays of the swampy areas

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Explanation of Plate.

Plate IX.

Fig 1—Aerial photograph showing the former stream courses in the St. Germain's district. Approximate scale 1 inch = 70 chains. (R A A.F. photo)

Fig 2- Aerial photograph of the Tooradin district, showing Sawtell's Creek and the tidal mudflats at the head of Western Port Bay, at low tide. The dark vegetation zone around the coast is mangrove swamp. ("Airspy" Regd., photo)


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[Proc Roy Soc Victoria 54 (N S) Pt I 1942]

Art VI —*A Survey of Soils and Land Utilization in the Parishes of Koo wee-rup and Koo wee rup East*

By A G GOUDIE B Agr Sc

[Read 12th July 1941 issued separately 15th April 1942]

Introduction

The parishes of Koo wee rup and Koo wee rup East cover an area of 81 square miles and contain the largest extent of reclaimed peat in the State The district still commonly known as the Koo wee rup Swamp is densely settled and has for many years had a reputation for high productivity The swamp area which occupies almost 95 per cent of the district was drained towards the end of last century The remaining area consists of low foot hills along the northern boundary of Koo wee rup East

This survey falls into two main sections namely the mapping and study of soil types and the collection of information concerning the farmers activities The latter section was greatly facilitated by the willing co operation of the Government Statist and his officers whose help is highly appreciated Many figures have been taken from the Statist s records which are collected annually from all farmers in the State and are grouped with the parish as the unit they are referred to as parish statistics The instantaneous cross section of the activities of some 500 farmers provides an accurate picture of the relative importance of the different types of farming All information has been so tabulated that no details of individual farmers have been disclosed The interpretation of these records was helped by interviews with 61 selected farmers The soils were surveyed thoroughly on these selected properties and the soil map of the district completed with the aid of numerous observations of profiles at roadsides and drains

Description of the Surveyed Area

Location

The location of the area is shown in fig 1 together with the railways and chief towns in the neighbourhood The district is excellently served by roads which make the two main Gippsland highways and railways readily accessible The most outlying parts are little more than 50 miles away from Melbourne and 20 miles away from either one of the market towns Dandenong or Warragul Dandenong is also the terminus of a suburban electric train service from Melbourne

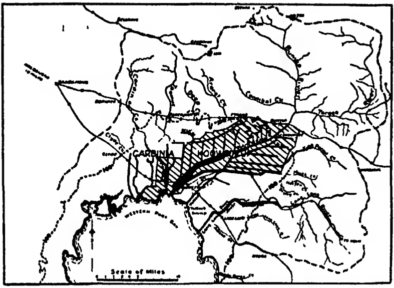

FIG. 1 Map of the Koo-wee-rup Basin and surrounding land, showing major drains. The area of this survey is shaded. The watershed (alternate dash and dot) and the 100 foot contour are also shown. Based on Map in (3)

POPULATION.

The total population of the area is about 3,500 of whom about 500 to 600 live in the principal township, Koo-wee-rup. There is a butter and cheese factory at Cora Lynn, a butter factory and milk depot at Bayles, and a flax mill at Koo-wee-rup. The flax mill is expected to employ 50 to 60 men during the peak periods, but the other two factories employ comparatively few.

TOPOGRAPHY.

The country slopes gently from the 100-ft. contour in the north and north-east to Western Port Bay in the south-west. The district is flat, except for the small hills along the northern boundary of Koo-wee-rup East. The grade of the main drain varies from 3 feet per mile in the lower reaches to as much as 10 feet per mile near Bunyip. The grades are so slight in the Dalmore area that the Cardinia drainage system is tidal for about 5 miles of its course. The flatness is sometimes broken by sandy areas, which usually take the form of meandering ridges from 1 to 5 feet high, and from a few yards to 1 or 2 chains wide.

The main eastern highlands of Victoria begin just to the north of the district.

GEOLOGY.

The soil boundaries (fig. 3) indicate the main geological boundaries. The district consists predominantly of recent alluvial

sand and clay together with large areas of peat, but the foothills of Tynong (in the north of Koo-wee-rup East) are of decomposed granite; also a narrow strip in the east of the district marked as podzol on the soil map consists of Pleistocene deposits.

Peat occurs in the central part of the district over an area of several thousand acres broken by only an occasional ridge of sand. Alluvial sand occurs in two main regions, both of which begin in the north-east as well-defined narrow ridges (too narrow to be marked on the map), and spread out as ridges and badly-defined sandy areas as they reach the flatter land in the centre of the district Clay alluvium underlies both peat and alluvial sand, and also occurs as a fringe around the peat. The surface 3 to 6 feet of this alluvium in the Dalmore district contains more organic matter than elsewhere in the district.

The clay alluvium from the head of the Main Drain down to Iona has a comparatively steep fall towards the south and south-west. This represents the fan delta region of the Bunyip River.

PHYSIOGRAPHIC HISTORY.

The sandy regions probably represent old river beds in which sand collected as it now collects in the Main Drain

Peat was formed and accumulated together with alluvium in the marshy areas beside the river courses Peat was so wide-spread and so deep between Cora Lynn and Catani that it seems likely that this area was, before reclamation, a sheet of water that was nearly filled in by the accumulation of peat and alluvium. This seems curious in view of the fact that there was a slope of as much as 3 feet per mile in this area. Evidently the reeds and rushes and in places the tea-tree (*Melaleuca ericifolia*) grew thickly enough to make the flow of water extremely slow. Peat seems to have accumulated mainly from the remains of reeds and rushes. It is doubtful whether tea-tree has made any important contribution to the peat, though it grew densely on the heavy soils of the district. Two transects of the swamp made in 1868 show mainly reeds, rushes, and water where peat has now been mapped, with a small area of stunted tea-tree noted on the eastern edge of the present peat.

After the district was reclaimed the marshy land shrank and consolidated, whereas the sandy ridges did not. Even before drainage many sand-ridges were exposed because the streams changed their courses, and thus reduced the waterlogging along their original beds. However, the old river beds often became filled with peat during their existence as lagoons, and after reclamation emerged as peat-covered sand ridges.

Inorganic alluvial clay (marked as "swamp fringe" on the soil map) occurs where the natural drainage is good enough to have allowed sufficiently long periods of aeration to prevent the

accumulation of peat The organic alluvial clay in the Dalmore district is an intermediate stage where much organic matter accumulated although more slowly than the clay giving a highly organic black clay

Climate

Average Annual Rainfall

There is a remarkable lack of exact climatic information in the closely settled country to the east and south east of Melbourne No stations in the surveyed area keep records of temperature humidity or evaporation however Koo wee rup and Tynong send monthly rainfall reports to the Weather Bureau at Melbourne Koo wee rup has kept records regularly since 1902 the mean annual rainfall until the end of 1939 is 30 8 inches and has ranged from 20 4 inches in 1938 to 41 8 inches in 1924 The rainfall rises sharply in the foothills to the north where Tynong Garfield and Longwarry (the last two stations being just outside the north boundary of the district) have an average of 34 6 34 9 and 35 3 inches respectively but probably all except the extreme northern fringe of the true swamp has an average close to that of Koo wee rup Personal records kindly supplied by local residents indicate that the central parts of the district may receive slightly less rain than the township of Koo wee rup

TABLE I—MEAN MONTHLY RAINFALL AND NUMBER OF DRY MONTHS AT KOO WEE RUP FROM 1902 1939 AND MEAN TEMPERATURE AND EVAPORATION AT MELBOURNE

—	January	February	March	April	May	June	July	August	September	October	November	December	Year
Rain (Koo wee rup)	1 7	182	248	251	2 4	[illegible]	261	281	294	320	276	259	3 078
Evaporation (Melbourne)	643	504	401	241	149	113	109	150	232	336	454	574	3 906
Temperature (Melbourne)	6 4	6 6	64 6	59 4	54 1	51 4	48 8	51 0	54 1	57 7	61 3	64 9	58 4
Number of times in 38 years rain below 1 inch (Koo-wee rup)	12	15	8	6	2	3	0	0	1	2	5	6	

(Rainfall is in points of one hundredth of an inch)

Distribution and Effectiveness of Rainfall

The climate is essentially similar to that described in more detail for the neighbouring district of Berwick (4) being cool and wet in winter and early spring and warm and dry in summer and early autumn The monthly rainfall averages for Koo wee-rup and mean figures for temperature and evaporation at Melbourne (as an approximation to local figures) are given in Table I While minimum temperatures are often lower than in Melbourne daytime conditions are probably similar

At first sight, monthly rainfall appears to be evenly distributed throughout the year; however, during the warmer months it is usually inadequate owing to high evaporation. Moreover, it is unreliable, as may be seen from the last line in Table I., which shows the number of times in 38 years that the rainfall for any one month has been less than 1 inch. Dry spells of more than one month are frequent. Thus, in 20 seasons out of 37, at least two successive months were too dry for growth (using Trumble's principle (9) that soil moisture falls below the permanent wilting point for plants when the ratio of rainfall to evaporation is less than one-third); ten seasons had at least three successive dry months (fig. 2).

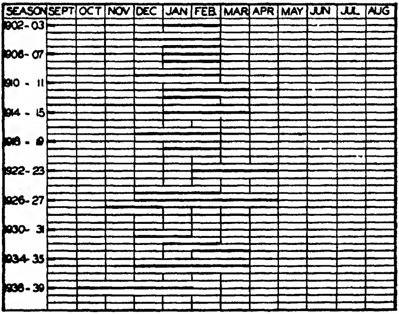

FIG 2.—Occurrence of spells of two or more dry months in succession at Koo-wee-rup. Each month that is marked with a heavy line had rainfall less than one third evaporation.

Perennial pasture species, maize, and summer forage crops are normally able to make some growth at such times because there are supplies of available moisture conserved in the subsoil. However, maize yields are consistently lower than those obtained further east, probably because of both lower rainfall and higher evaporation. Orbost, which is famous for its maize yields, receives during January and February an average of $1\frac{1}{2}$ inches more rain than Koo-wee-rup, but there are no data concerning evaporation.

Pasture production normally shows a well-marked peak in spring, when temperatures are suitable for growth, and the rainfall reaches a maximum and is reliable. On the other hand, rainfall is unreliable in early autumn. If early falls in March are followed by sufficient rain to keep the soil moist throughout the autumn, then both annual and perennial pasture plants have time to develop a deep root system while the soil is still warm. Such well-established plants make some little growth during the cold wet months. If the autumn "break in the weather" is late, pastures make little growth until September.

FROST.

Most reclaimed swamps suffer acutely from frost (1, 2). The Koo-wee-rup swamp is no exception, and receives more severe and frequent frosts than surrounding districts or Melbourne. This may be connected with the drift of air from the high land on the north and east. Frosts damage potatoes and maize even during the summer; ground frosts were reported in the district on 13th January and 13th February, 1940, when the respective ground minima at Melbourne were 42·9 degrees and 41·4 degrees. Though local conditions are thus peculiar, there are no precise records of minimum temperatures anywhere near Koo-wee-rup; in view of their great importance to potato and maize growing, this is surprising.

Frost damage is by no means uniform over the whole district. Crops grown on heavy "Swamp Fringe" soils (see p. 103) suffer less frequently than those grown on the peaty and burnt peaty soils Certain Koo-wee-rup farmers say that frost damage is more severe on unburnt peaty soil than on adjacent burnt soil, and more severe on tilled soil than on adjacent untilled soil. This coincides with American observations, e.g., Alway (1) in Minnesota. These differences can be predicted on account of relative conductivity—that is, the looser the surface soil, the slower the transfer of heat from the warmer lower layers to the chilled surface. Bouyoucos and McCool (2) have measured a great number of minimum soil temperatures over a period of four years. The following collection of minimum ground temperatures taken from adjacent plots on the same night is typical of their observations.

Clay loam (compact), 36·2°F.
Peaty soil (compact), 31·0°F.
Peaty soil (cultivated), 28·0°F.

Valuable frost-liable crops such as sweet corn would probably repay the expense required for the operation of heating equipment during frosty nights. The dew point on the previous evening (calculated from dry-bulb and wet-bulb thermometers) has been used for predicting the likelihood of frosts in orchards; its use could probably be extended to cover these Koo-wee-rup crops.

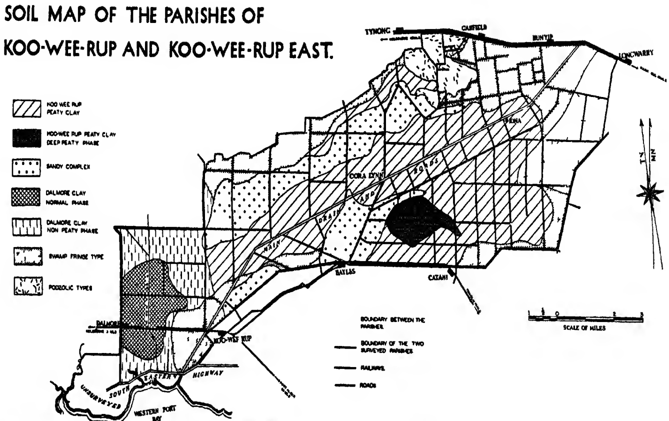

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Fig 3.—Soil map of the Parishes of Koo-wee-rup and Koo-wee-rup East

[Page 99-100

Soil Map and Description of Soil Types

Seven soil symbols are shown on the soil map of the parishes of Koo wee rup and Koo wee rup East Six of these represent soils in the swamp group The other represents a collection of miscellaneous podzols occurring on higher ground these are of small extent and are not representative of the district The soil map is essentially a sketch map—the product of a reconnaissance survey—and is deliberately produced on a small scale In general the uncertainty of any boundary does not exceed 400 yards In the north west of the district the various transition phases between Dalmore clay Koo wee rup peaty clay and Swamp fringe are in places three quarters of a mile wide The doubtful areas have been divided between the major soil types concerned Also in the same area there was some difficulty in deciding the boundary between Koo wee rup peaty clay and the sandy complex because the sandy types are scattered and poorly defined Any more detailed mapping in the sandier parts would call for an immense amount of work since the pattern of the sandy strips is so intricate

SWAMP TYPES

The various streams coming fr m areas derived largely from granite have deposited sediments which vary in texture from coarse sand or gravel in the bed of the stream to clay where water has spread out and remained stagnant

Because of the frequency and duration of swampy conditions waterlogging is the main pedogenic factor influencing the nature of these soil types Peat accumulated where waterlogging was continuous or nearly so Peat deposits were largely modified by inorganic sediments which settled during periods of flooding

(1) *Koo wee rup Peaty Clay (normal phase)* This is the most widespread type and it covers a large area on both sides of the middle reaches of the Main Drain The characteristic profile is —

- Horizon 1 (0–9 inches)—brownish grey peaty clay
- Horizon 2 (9–17 inches)—dark grey gritty clay
- Horizon 3 (17–33 inches)—grey gritty clay with some yellow and red mottling
- Horizon 4 (below 33 inches)—light grey gritty clay yellow and red mottling

The gritty character is caused by the presence of angular fragments of coarse sand and gravel both quartz and felspar

Horizon 1 normally contains from 15 to 30 per cent organic matter which so modifies the clay as to give it a light loamy texture However some areas of peaty clay which usually only had a thin layer of peat to begin with are now somewhat cloddy because the organic matter has been depleted by oxidation to

about 10 per cent. Horizon 2 has an open, freely draining structure despite its high clay content. This is partly explained by the high content of organic matter, and partly by the presence of root tracks, yabby holes, and numerous persistent cracks. Lower horizons are impervious to water.

(1*b*) *Koo-wee-rup Peaty Clay (burnt peat phase):* This phase cannot be mapped in detail because of the intricate way in which it is associated with the normal phase, and also because of the great variation in the effects of burning. All burned patches have therefore been included in the normal phase on the soil map The deep burn, which usually occurred on relatively high ground, destroyed the organic matter right down to the dark-grey clay, although a thin surface crust commonly remained unburnt and subsequently enriched the ash with organic matter. Deep burning has occurred in several patches, some of which cover a square mile in area Shallow fires have been widespread and occurred when the water table was high enough to protect some of the peat from burning The ashes from these burns soon mixed with unburnt peat, and the mixture worked down to give a soil of a similar nature to the normal unburnt type.

(1*c*) *Koo-wee-rup Peaty Clay (deep peat phase).* This phase contains a layer of true peat up to a foot in thickness between horizons 1 and 2 of the normal profile Remains of *Phragmites,* the bulrush *Typha,* and tea-tree were identified in this peat, and numerous unidentified plant remains were observed penetrating the underlying dark-grey clay. This peat consists approximately of 45 per cent. organic matter, 45 per cent. clay and 10 per cent. of coarser mineral fractions

(2) *Sandy Complex* Sandy types are intricately associated with both Koo-wee-rup peaty clay and the swamp fringe type. " Sandy Complex " is mapped wherever a sandy type constitutes more than 20 per cent. of the area. Nearly all the land so mapped is a complex of sandy types with Koo-wee-rup peaty clay; the main exception is a complex of sandy types and the swamp fringe type near Bayles. Isolated ridges run through all the other soil types except the podzols, but they are insignificant and have been ignored.

The complex occurs mainly in the north of the district as a thin strip running in a south-westerly direction. It also occurs to the south of the Main Drain as the north-eastern end of another parallel strip which crosses the parish boundary at Bayles.

The typical sandy profile is :—

Horizon 1 (0–4 inches)—grey loamy sand.

Horizon 2 (4–45 inches)—light-grey loamy sand.

Horizon 3 (45–50 inches) light-grey clayey sand with some yellow mottling.

Horizon 4 (below 50 inches)—light-grey gritty clay, with yellow and red mottling.

The type varies in many respects. The second horizon may be from 2 to 5 feet deep or even more. The texture of the first two horizons may vary from sandy loam or peaty loam, to almost pure sand. The sand fraction may contain almost any proportions of fine sand, coarse sand or gravel. In general, coarse sand and gravel predominate in the north-east and fine sand in the south-west.

The sandy areas are quite commonly in the form of well-defined ridges (see p. 95) This is especially true in the north-east of the main strip and throughout the southerly strip. Much of the main strip consists of ill-defined sandy areas in which horizon 1 is peaty loam, underlain by sandy loam. These areas are usually slightly elevated, but bores must be dug to make certain that the subsoil really is sandy

Compared with other swamp types, these soils have a low water-holding capacity. Pastures and crops grown on this type therefore dry off much earlier in the summer. On the other hand, sandy areas are normally more productive than other swamp types during really wet winters. Ground water stands remarkably high here; a permanent water supply is commonly obtained by scooping shallow dams out of suitable ridges. The water level of some dams was within 8 feet of the surface throughout the 1938-39 drought.

(3) *Swamp Fringe Type*. This surrounds the Koo-wee-rup peaty clay and probably represents the edge of the old swamp basin which was not waterlogged intensely enough to permit the accumulation of more than a few inches of peat.

The following profile is typical:—

Horizon 1 (0–10 inches)—grey clay loam.

Horizon 2 (10–16 inches)—light-grey clay loam.

Horizon 3 (below 16 inches)—light-grey clay, with yellow and red mottling.

The transition from this to peaty clay is very gradual, and every intermediate type exists. The intermediate types are distinguished from Koo-wee-rup peaty clay by their greater cloddiness. The subsoil in certain areas becomes "spewy" when conditions are wet enough. Fine brownish-red mottling due to waterlogging often occurs in the upper horizons, giving the ploughed soil a brownish-grey appearance. The large area of soils developed on flat land to the east of the surveyed district (Yannathan and Yallock) are, judging by the few exploratory samples which were examined, very similar to the brownish-grey swamp fringe type.

(4*a*) *Dalmore Clay (normal phase):* This type occurs in a continuous patch in the region of the Cardinia drainage system (fig. 1). The following profile is typical:—

Horizon 1 (0–7 inches)—black friable clay.

Horizon 2 (7–30 inches)—black plastic clay becoming somewhat lighter in colour with depth.

Horizon 3 (30–34 inches)—dark-brown decomposing peat.

Horizon 4 (below 35 inches)—grey gritty impervious clay with yellow mottling.

The first horizon is of a very workable nature, despite the high figure for clay (Table VII). This is explained by its 15 per cent. of organic matter Small amounts of red ash commonly seen in the surface horizon are relics of fires used by settlers during the clearing operations. Horizon 2 contains the same mineral fractions as Horizon 1, but the clayey texture is not greatly modified by organic matter. Below this horizon is a peculiar deposit of decomposed peat which, in the central regions of this phase, reaches a thickness of 2 feet. Seeds of the sedges *Scirpus* and *Lepidosperma* were identified in this peat.

(4*b*) *Dalmore Clay (non-peaty phase):* This phase is almost identical with that of the normal phase, except for the absence of Horizon 3. It occurs as a narrow fringe around the eastern and southern boundary of normal Dalmore clay, but extends to the north and north-west for a considerable distance beyond the boundary of the district. This phase appears to have an inferior surface texture which corresponds to its smaller reserve of organic matter than normal Dalmore clay (Table XI). This is to be expected because, being on higher ground, the soil would be formed under conditions less favourable to the accumulation of organic matter. Some of the outlying representatives of this type in the neighbouring parish of Sherwood are intractable in the surface and have an impermeable subsoil, which cannot be improved by under-drainage. These soils are very similar to Eumemmering clay (4); the non-peaty phase of Dalmore clay within the surveyed area is transitional to this type.

(4*c*) *Dalmore Clay (salty phase):* This is represented by a very small unmapped patch of land near the sea which is periodically flooded with salt water. The clay has been solonized and supports salt marsh plants and, in the less affected areas, salt-tolerant plants.

MISCELLANEOUS PODZOLS.

The intensely podzolized type developed on decomposing granite in the north of the parish of Koo-wee-rup East has a

profile very similar to that of Harkaway sand, which occurs to the north of Berwick. The following profile is typical:—

Horizon 1 (0–4 inches)—grey loamy sand.

Horizon 2 (4–13 inches)—light-grey clayey sand

Horizon 3 (13–30 inches)—grey heavy clay, with yellow and red mottling.

Horizon 4 (below 30 inches)—decomposing granite.

Another group of podzols and deep sandy types occur along the eastern boundary of Koo-wee-rup East. They are derived mainly from unconsolidated tertiary deposits.

Land Utilisation.

General Considerations.

Historical Introduction.

The settlement of the surrounding country had begun by the middle of last century, and by 1880 a cheese factory was established at Caldermeade, supplied by one herd of over 200 cows. Materials and provisions were brought up the Yallock Creek by boat from Tooradin because the tea-tree in the Dalmore district was almost impassable. The Koo-wee-rup Swamp during this period was overgrown with tea-tree, reeds and rushes, with many lagoons The land was occasionally leased for grazing During the summer, animals were driven along the relatively dry sand-ridges and obtained some low-grade feed around the marshy reed beds and among the tea-tree on higher ground

In 1882, Parliament considered draining the swamp and selling the reclaimed land to pay for the projected South-Eastern railway line. The proposal was rejected, but served to draw attention to the possibility of opening up a valuable new agricultural area. Such a scheme appeared very desirable because the fertility of reclaimed land and the cost of drainage were usually estimated optimistically. In 1888 specifications were drawn up for the drainage of the swamp and operations started under the direction of a Swamp Board. The Public Works Department soon assumed control and the operations continued as a scheme to relieve some of the unemployment caused by the bursting of the land boom in the early 'nineties.

The early reclamation works consisted of the Main Drain, which takes the Bunyip River across the Swamp to Western Port Bay, and a series of tributary drains which collect minor streams entering the Swamp. Much of the excavation was carried out with shovels and barrows; the labourers endured very bad conditions owing to the marshy nature of the land. The embankments of excavated mud were often the driest land available and had to be used both as roads and as the men's camping-grounds.

The scheme of employment was that the men were allotted 20-acre blocks on the edge of the swamp and were given half-time employment on the drainage works, receiving 6s. 8d. per day. They were allowed to keep their blocks so long as they effected improvements to the value of £3 per month. Under this scheme 895 blocks had been allocated by April, 1894 General selection began in 1900, shortly after a big fire had burnt much of the tea-tree and other swamp debris. Prices of the blocks sold to settlers ranged from £1 10s. to £6 10s. per acre.

Newly-reclaimed peat land presented peculiar difficulties The dry peat was at first so fibrous and incoherent that it would only support the weight of light animals Calves were frequently used to effect preliminary consolidation because they had large feet relative to their weight. Buried tea-tree roots had then to be removed after the peat had settled and exposed them. Cropping and dairying were begun as soon as it was safe to bring heavier animals on to the peat However, horses' feet and implement wheels had often to be wrapped in bags to prevent their sinking too far; cows formed sunken consolidated tracks leaving loose hummocks which later had to be levelled by hand. Peat fires were commonly lit in order to destroy the dry, loose peat, the buried tea-tree roots and the surface debris.

The primary drainage system could not cope with floods following heavy rain in the hills. It was enlarged in 1902, and again in 1913-16, and is at present being remodelled and enlarged in the light of experience gained from the disastrous flood of 1934.

In 1917 the Government drainage scheme was extended to include the existing private reclamation schemes at Dalmore and Cardinia. The drainage systems of these areas are also being improved at the present time (6). The cost of the new works will bring the total drainage costs of Koo-wee-rup and Cardinia to £600,000; even then, neither district will be completely immune to extensive floods in seasons of very exceptional rainfall, though these are unlikely to occur oftener than about once in ten years.

FLOODING.

The total catchment area of the Koo-wee-rup Swamp Basin is 450 square miles, and its average annual rainfall is 44 inches. The Main Drain carries the runoff from about 260 square miles of hilly to mountainous country, some of which receives nearly 70 inches. It is therefore not really surprising that there have been nine floods recorded in the district during the last 29 years. These floods have come during every season except the height of summer. There is no exact information about the area flooded, but the damage to crops has been considerable. The drainage system has always disappointed settlers and engineers in its capacity to protect the district from floods, owing to the repeated underestimation of the intensity of extraordinary floods.

The flood of 1st December 1934 was three times greater than any which have occurred since measurements began in 1907, and six times greater than the original estimate of an extraordinary flood. Potato and maize crops were ruined and nearly 3,000 head of stock were drowned. The water entered houses throughout the district, and stood 6 feet high in the streets of Koo-wee-rup. This catastrophe produced a profound reaction. Cropping, which was in any case becoming unpopular, gave way almost entirely to dairying; land values dropped and settlers agreed to a really expensive drainage system. This flood was, in fact, due to a freak storm. The rainfall at Warragul for 24 hours was 7·47 inches the previous highest 24-hour fall during 52 years was 3·49 inches. A storm of such intensity is most unlikely to recur during a lifetime, but the impression of insecurity still influences agriculture in this district.

There has certainly been some increase in runoff because forest cover in the catchment area, especially in the headwaters of the Tarago, has been seriously damaged by fire and axe. However, in some areas (notably in the Strzlecki Ranges) forest has been replaced by first-class pasture which can probably retain water as efficiently as virgin forest.

The maintenance of drains has been a difficult problem in this district. Apart from the growth of tea-tree and reeds, drain capacities have been reduced owing to shrinkage of peat and to siltation. This shrinkage, which averages 3 to 4 feet over much of the district, was the main problem in the early days. All the affected drains had to be re-excavated down into the clay subsoil. Siltation mainly affects the Main Drain The problem is not a recent one. By 1916 the Main Drain had deposited a layer of sediment 2 feet thick a mile and a half out to sea and there was up to 6 feet of sand in the bed of the drain (3) The upper reaches have scoured to a depth of nearly 25 feet and at present there are approximately 80,000 cubic yards of sand being deposited annually in the bed of the drain below Cora Lynn. The sand is ideal for concrete and is readily loaded into trucks by means of a suction dredge. However, it is accumulating more rapidly than it is being removed.

Agricultural Development.

The only exact information on farming activities in the district is contained in parish statistics, which were first collected in 1907. Statistics have been kept continuously since then, giving a quantitative record of agricultural development. The agricultural income of the district in 1907 was chiefly derived from 1,300 milking cows, 2,500 other stock, and 1,600 acres of root crops.

The fluctuations and trends of the main farming activities (potatoes dairying oats for hay and sheep) are shown in figs 4 and 5 Fig 6 has been included to show the similar trends in number of stock in the two parishes the trends of other activities are also similar consequently the statistics of the two parishes have been combined in this paper

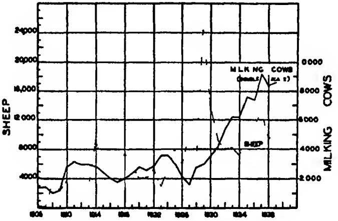

Fig 4 Numbers of sheep and milking cows 1906 1939 in the parishes of Koo wee rup and Koo wee rup East

The fluctuations of the potato crop (fig 5) are particularly interesting The district quickly established a reputation for potatoes and the acreage increased from 1 300 in 1907 to 15 800 in 1923 The subsequent decline to 1 400 acres in 1939 40 is

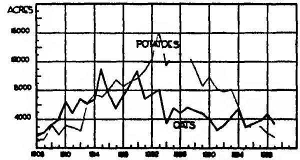

Fig 5 —Acres under potatoes and oats 1906 1939 in the parishes of Koo wee rup and Koo wee rup East

partly a reflection of the State wide difficulties of the potato-growing industry caused by the low prices during the early 'thirties Further Koo-wee rup farmers suffered an almost complete loss of their crop in the disastrous flood of 1934 Added to these misfortunes are the usual hazards of destructive spring

and summer frosts, the attacks of potato moth (*Phthororimaea operculella*) and "sore-eye" (*Bacterium solanacearum*) and the difficulties of a market which fluctuates considerably from month to month These monthly fluctuations are an unfavourable contrast to the relatively unvarying market price for milk and milk products Many Koo wee rup farmers think that potato yields are lighter now than they were twenty years ago However statistics collected over the last fifteen years for county Mornington suggest that slightly higher yields have been obtained recently than during the peak years of potato growing

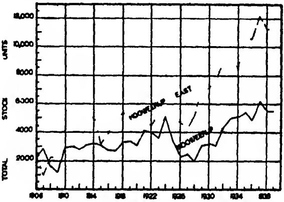

Fig 6 Numbers of stock in the parishes of Koo wee rup and Koo wee rup East 1906 1939 A stock unit is defined as 1 cow heifer or horse 2 calves 10 sheep or 15 lambs

Most farmers have turned from growing potatoes to dairying The milking cow population which had varied between 1 600 and 3 700 for the twenty years preceding the slump in potatoes rose steadily to 9 700 by 1937 (fig 4) The number has fallen slightly since then mainly on account of the drought of 1938 39 but it may reasonably be expected to increase with better management and improvement of pastures

Fig 5 shows that between 1911 and 1923 over 6 000 acres of oats were grown annually for hay and on two occasions the figure exceeded 10 000 acres (or one fifth of the total area of the district) Hay was then grown as a cash crop in rotation with potatoes but is nowadays only used as supplementary fodder for dairy cows This accounts for the smaller acreage during the last ten years Yields of hay calculated over the last 30 years normally vary from $1\frac{1}{4}$ to 2 tons per acre

In addition to these major activities fairly large areas of grain crops (mainly wheat, oats, and maize) have been planted at various times

During the late twenties over 1 000 acres of wheat were grown annually, the highest acreage being 4,000 in 1928 Yields

averaged 28 bushels per acre over a number of years and some farmers reported having harvested 40 bushels per acre A few hundred acres of oats were harvested for grain over the same period yields being somewhat lower than those of wheat

The area of maize for grain to day is almost equal to that of potatoes and has remained steady during the last fifteen years Annual wholesale price averages are far steadier than those of potatoes and onions

In addition to these larger areas of crop farmers of the district have for many years grown smaller areas of onions carrots peas asparagus pumpkins melons and other minor cash crops

Individual Occupations

Definition of Farm Types

The occupations of farmers have been analyzed by using the parish statistics for 1939 40 Occupation and size of holding are classified in Table II There are 438 farmers whose production is considered to be significant a farmer who is so classified has as a minimum 7 cows or 5 acres of cash crop or 80 sheep or 10 head of other stock This leaves 78 men whose names appear on the records as farmers but who are classified here as unproductive

Table II —Distribution of Farmers on Basis of Occupation and Size of Holding

Size of Holding (Acres)	Number of Farmers of Given Occupation								
	Dairy	Dairy and Cash Crop	Cash Crop	Cash Crop and Other Stock	Sheep	Dairy and Sheep	Unproductive	Miscellaneous Graziers	Total
16–20	17		5				33	1	56
21–40	35	5	12				19	3	74
41–60	68	17	10		1		8	1	105
61–80	41	13	6				6	1	67
81–100	49	8	4	3	2		2	1	69
101–120	26	10	3	1		1	3		44
121–150	20	7	1	1	3	2	2		36
151–200	15	4	8	1	1	2	2	2	35
201–300	6	1	1	1	1	2	3	4	19
>300	4		1	3	1			2	11
Total farmers	281	65	51	10	9	7	78	15	516
Total acres	24 410	5 775	4 540	2 505	1 743	2 356	3 740	3 440	48 509
Percentage of total area	50	12	9	5	4	5	8	7	100
Average size of farm (acres)	87	89	89	250	194	337	48	230	94

As Table II shows the majority of men in the unproductive class are so because their farms are very small Other men with larger farms are unproductive because much of their land is 'uncleared The 2 900 acres of "uncleared" land in this

district consists mostly of salty land near the sea and of podzolic land under eucalypt cover in the north and north-east of the Parish of Koo-wee-rup East The "unproductive" class necessarily includes a few poultrymen (since poultry are not now included in parish records) and graziers who happened to be running no stock when the statistics were collected

The following is the basis of the classification of productive farmers Men with at least 7 milking cows 5 acres of cash crops, 80 sheep or 10 head of other stock are grouped as dairymen, cash crop farmers, sheep farmers, or "miscellaneous graziers" respectively Farmers who derive 20 per cent of their income from each of at least two of these activities are classed as 'mixed"—dairy with sheep dairy with cash crop, and cash crop with other stock For the purpose of this classification 1 acre of cash crop two milking cows or twenty sheep are considered to produce the same income

Forty nine farmers were selected from a recommended list and personally interviewed in order to obtain more detailed information concerning farm activities pasture types and the history of the district These farms were scattered fairly evenly over the whole district In addition twelve small farms were selected at random and visited because the recommended list contained too great a proportion of large farms to be truly representative Some of the farmers with less than 40 acres have independent sources of income Most of the remainder have to do some work on roads, drains, or other farms, in order to maintain a reasonable standard of living

DAIRY FARMERS

There are 281 dairy farmers who derive more than 80 per cent of their income from dairying The distribution of herd size and farm acreage is given in Table III, which shows that herds of 16-20 cows and farms of 41 60 acres are most frequent

TABLE III—DISTRIBUTION OF DAIRYMEN ON BASIS OF SIZE OF FARM AND SIZE OF HERD

Size of Holding (Acres)	Number of Milking Cows										Total Farmers
	- 10	11 15	16–20	21 25	26–30	31–35	36–40	41–50	51–60	>60	
16– 20	10	6	1								17
21– 40	7	13	14	1							35
41 60	8	18	25	14	1	2	1				68
61– 80		8	15	8	6	4					41
81–100	2	6	5	11	15	5	3	1	1		49
101–120		1	2	4	8	4	5	2			26
121–150			2	4	2	5		6		1	20
151 200	1		2		2	4	2	2		2	15
201–300			3						2	1	6
>300						1	2	1			4
Total Farmers	28	52	60	41	34	25	13	12	2	4	281
	Small dairymen			Medium dairymen				Large dairymen			

The activities of dairymen are most conveniently described by dividing them into three groups according to size of herd, viz., those with up to 20 cows (small dairymen), those with 21-40 cows (medium dairymen), and those with more than 40 cows (large dairymen).

There are 149 small dairymen, the average holding being one of 58 acres with 15 milking cows, and other stock equivalent to 11 milking cows. Of this 58 acres, 51 acres consist of grassland, 20 acres of which are annually topdressed at the rate of 1·4 cwt. per acre and 7 acres are sown to supplementary green fodders.

There are 113 medium dairymen, the average holding being one of 106 acres with 29 milking cows and other stock equivalent to 15 milking cows. (For stock equivalents see under fig. 6.) Of this 106 acres, 90 acres consist of grassland, 42 acres of which are annually topdressed at the rate of 1·5 cwt. per acre and 16 acres are sown to supplementary green fodders.

There are nineteen large dairymen, the average holding being one of 176 acres with 55 cows and other stock equivalent to 31 milking cows. Of this 176 acres, 145 acres consist of grassland, 85 acres of which are annually topdressed at the rate of 1·4 cwt. per acre and 31 acres are sown to supplementary green fodders.

Milking machines have increased almost ten-fold in the last seven years, and are now operated by over half of the medium and large dairymen and by one-ninth of the small dairymen. Petrol, kerosene, or diesel engines are usually the source of power, although electric motors are used on some farms.

Many dairy farmers supply whole milk to Melbourne, either directly or through the milk depots at Bayles and Longwarry. Others supply whole milk or cream to the butter factories at Bayles and Longwarry, and to the cheese factory at Cora Lynn. Whole milk, other than city contract supplies, is paid for on a butter-fat basis, and commands a small premium over cream to allow for the factory value of skim milk.

Supplementary Fodder Crops: Eighty per cent. of dairymen grow supplementary green fodder, most of the remaining 20 per cent. have only small herds. More than half the dairy farmers grow oats to supplement pastures during the winter; cows turned in to graze the crop do not "bog up" the plants as they would in other districts of comparable rainfall because the excellent structure of these highly organic soils allows excess water to pass quickly through upper horizons and then laterally to artificial drains.

Farmers usually discontinue grazing oats in August so that the crop can later be cut for hay. Some farmers harrow in red clover seed after the last winter grazing, harvest the mixed crop,

and retain the red clover stand as a good summer and autumn reserve of green fodder. Red clover makes good growth in this district, if it is properly established; it is, therefore, undesirable to sow and graze it with oats during the winter because the crown of the young plant is exposed to damage.

More than half the dairymen of the district grow maize, which is usually fed as a soiling crop during the pasture shortage of late summer and autumn. Some dairymen find that pastures are inadequate to provide succulent feed until maize is ready to cut, so that fairly large areas of millet and rape are sown

Dairymen who supplement pastures with green fodder crops grow on an average half an acre per cow of oats, rape, or millet, or one-quarter acre per cow of maize Table IV shows that some dairymen in all three classes grow a combination of two or even three of these crops in an endeavour to maintain production throughout the year.

TABLE IV—DISTRIBUTION OF DAIRYMEN ACCORDING TO THE TYPE OF SUPPLEMENTARY GREEN FODDER GROWN

Classification by Size of Herd	Total Number of Men in the Group	Growing No Supplementary Green Fodder	Oats Alone	Maize Alone	*Other Green Fodder Alone	Oats and Maize	Oats and/or Maize and Other Green Fodder
Small dairymen	149	35	26	25	6	30	27
Medium dairymen	113	17	19	16	2	23	36
Large dairymen	19	1	4	4	.	7	5

* Mostly Millet or Rape

Pasture Types Pastures are by far the most important part (probably about 80 per cent.) of a milking cow's diet in this district. Among dairymen, the area of grassland is about six times as great as the total area of green fodder crops.

Some 4,600 acres of this 35,000 acres of grassland were inspected during the autumn and spring of 1940, and four major types were distinguished; (*a*) one in which dense perennial rye grass is usually the dominant and in some cases the only species present, with cocksfoot, white clover, and red clover as the usual associates; (*b*) rather thin stands of perennial rye grass, a fairly dense stand of subterranean clover and varying amounts of Yorkshire fog, cocksfoot, and "water couch" (*Paspalum distichum*); (*c*) unimproved native pastures in which wallaby grass is dominant; and (*d*) a characteristic "volunteer" pasture association which appears after cropping. This usually consists of weeds and subterranean clover, but near the Main Drain, white clover also commonly volunteers. The usual weeds are rushes, thistles, flatweed, and sorrel; bracken, ragwort, and blackberries are

seldom seen on the farms, but the reed, *Phragmites,* is common over large areas of this volunteer pasture, although it can be completely suppressed by proper management.

Only 15 per cent. of the area of inspected farms consisted of the dense perennial type (*a*). By far the commonest type was the subterranean clover–perennial rye grass association (*b*), which has one serious drawback on light peaty loams and burnt loams, namely, that cows pull up many rye-grass plants during summer and autumn while soils are dry and loose and there is no binding mat of subterranean clover The unimproved native pastures (*c*) were observed only in small patches on the poor podzolic soils in the north and north-east of Koo-wee-rup East. Volunteer pasture (*d*) constituted 35 per cent of the area inspected.

Topdressing and Management: Topdressing only began during the late twenties; the average area topdressed annually rose to 17,000 acres (or one-half of the total grassland area) in 1938-40 Parish statistics unfortunately group applications of lime and superphosphate under the common heading of "manure." However, the difficulty is not as serious as it sounds, because inquiries among farmers show that at most one-twelfth of the topdressed area receives lime. The average rate of application of "manure" for 1939 was 1·4 cwt. per acre.

The Victorian Pasture Improvement League have carried out pasture trials at Caldermeade, 3 miles east of Koo-wee-rup, on soil resembling the normal swamp fringe type, and have shown that 2 cwt. per acre of superphosphate, applied annually, markedly increases the yield of pasture. Yields of dry matter per acre from mown plots ranged from 25 cwt. in the drought season of 1938–1939 to 82 cwt in 1936-37 with an average of 55 cwt. over eight seasons. (The season is reckoned from 1st March to 28th February.) Although there is no doubt that topdressing is well worth while in the Koo-wee-rup district, it may easily be less so than elsewhere because of the residual effect of previous heavy applications of phosphate to the land.

There has been great interest in lime in this district as elsewhere in southern Victoria, but there is no evidence of an increase in yield of pasture subsequent to liming on the Caldermeade plots. In fact, other fertilizer treatments (nitrogen, potash, lime together with 2 cwt. of superphosphate; also 3 cwt. superphosphate) do not produce a significantly greater response than 2 cwt. superphosphate alone.

The Caldermeade plots are cut and weighed at convenient intervals; they normally yield two-thirds of their annual bulk between mid-August and mid-November, a further one-sixth before the end of December, and the remaining one-sixth in the following eight months. It is clear from these observations that

conservation of the spring pasture surplus is a necessary adjunct to topdressing. In 1937—a fairly normal year—the average yield of grass hay per acre was one and a quarter tons, yet only 1 acre in every fourteen of grassland was cut for hay in this year. Evidently many farmers in the district have not yet realized the possibilities of this phase of pasture management. The exceptionally severe drought of 1938-9 and the abnormally vigorous autumn growth during 1939, following the fall of 7 inches of rain at the end of February, make it misleading to quote more recent figures as representative. Some farmers who baled their hay and who should therefore have reliable estimates, reported 3 tons per acre for the 1939 cut.

Among the farmers visited, nearly all harrow their pastures to spread cow manure, and none believe in the now obsolete practice of mutilating the sward as a means of increasing pasture growth. Ordinary harrows are commonly used with or without a reduction in the draught of teeth made by fitting a board along the front row of teeth, or by packing the whole set with wire netting.

Farms are usually divided into paddocks of 5–10 acres, yet only a few farmers carry out systematic rotational grazing. However, the bulk of fodder produced during summer, autumn, and winter is so small that it is doubtful if subdivision is worth while on mediocre pastures. But if the fences are already present, the farmer may as well practise rotational grazing and obtain the small increase in growth which is known to occur under this treatment.

Rate of Stocking: The average rate of stocking on dairy farms is one stock unit per 2·4 acres (a stock unit is arbitrarily fixed at one dairy cow, dry cow, heifer or horse, 2 calves, 10 sheep, or 15 lambs). Farms of small area (fig. 7) are more heavily stocked than those of large area; the median rate of stocking on farms of less than 60 acres is 1·9 acres per stock unit compared with the corresponding figure of 2·7 for farms of more than 120 acres.

Relation of Superphosphate to Rate of Stocking: The exact relation between topdressing with superphosphate and rate of stocking cannot be worked out from the statistical records for two reasons. Firstly, there is a difficulty about the records themselves, since lime and superphosphate are grouped together as "manure." Secondly, many small farms are topdressed only in alternate years. However, enough farms are topdressed regularly to yield the surprising fact that there is hardly any correlation between topdressing and rate of stocking.

It is worth while to consider some of the reasons for this low correlation because pastures in this district certainly benefit from the application of superphosphate. A major reason is the residual effect of previous crop and pasture dressings. Dressings

of half a ton of superphosphate were, and still are, commonly used on potatoes. The amount of phosphorus removed by a 4-ton crop of potatoes corresponds to only 64 lb. of superphosphate, so that, after a number of years of intensive potato cropping, a considerable, though diminishing residual effect is quite natural. There are still men, especially in the Dalmore area, who regularly sow pasture in rotation with potatoes, and their pastures are outstandingly good. Supplementary fodders also raise the carrying capacity of a farm. Nearly all the 20,000 bags of grain, bran, and pollard which are normally bought every year are fed to milking cows. Further, the exceptionally large and well-distributed area of road and drain frontage is commonly used to relieve the strain on over-grazed pastures.

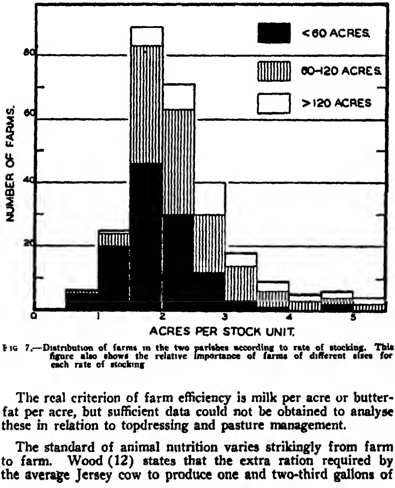

FIG 7.—Distribution of farms in the two parishes according to rate of stocking. This figure also shows the relative importance of farms of different sizes for each rate of stocking

The real criterion of farm efficiency is milk per acre or butter-fat per acre, but sufficient data could not be obtained to analyse these in relation to topdressing and pasture management.

The standard of animal nutrition varies strikingly from farm to farm. Wood (12) states that the extra ration required by the average Jersey cow to produce one and two-third gallons of

milk is equal to its daily maintenance ration of five starch equivalents. Over-grazing at the expense of milk production is, therefore, alone sufficient to explain the abnormally high stocking of some small farms, and in particular of small farms not topdressed at all.

CASH-CROP FARMERS.

General Discussion· Of the 126 farmers growing more than 5 acres of cash crops, 51 derive more than 80 per cent. of their farm income from this source. Their average holding is 90 acres, half of which is cropped; but at Table II shows, a few large farms considerably affect the average size.

Stocking is generally very light, and the average man has three or four horses and one or two cows for domestic use. Nearly a quarter of the farmers have tractors as well.

The activities of the cash-crop farmers, as shown in Table V., vary widely. Potatoes and maize for grain occupy an area equal to the combined area of all the special crops, viz., sweetcorn, asparagus, onions, melons, pumpkins, carrots, parsnips, cabbages, parsley, and peas, the last seven of which have been grouped as "Other Vegetables" in Table V. Of the "Other Vegetables," green peas are by far the most important and, together with asparagus and sweetcorn, supply an appreciable proportion of the Victorian canned vegetable industry.

TABLE V—ACTIVITIES OF THE FIFTY-ONE CASH-CROP FARMERS.

—	Potatoes.	Maize for Grain	Sweet-corn.	Asparagus.	Onions	Other Vegetables
Total area (acres)	639	585	224	150	75	647
Number of growers .	36	23	2	1	10	25
Average area grown (acres) .	18	25	112	150	7	26
Number growing one crop	8	7	..	..	.	4

The texture of soils in this district is generally well suited to cash cropping, but much of the most suitable land is infested with *Phragmites*. This reed is very hard to control in cultivated paddocks because it grows quickly from a deep system of rhizomes; in fact, many people believe that cultivation causes a more prolific reed growth. This is probably correct except where cultivation is very intensive. The vigour of the reed can be greatly reduced by establishing a good pasture stand and keeping it well grazed for several seasons.

Potatoes: The better farmers select their seed from the previous season's crop and store it in racks under trees which allow sufficient light and provide shelter from the weather.

Potatoes are usually sown during October or early November so that nearly half of the crop can be dug by the end of February The normal rate of seeding is 10 to 15 cwt per acre with up to 10 cwt or even more of superphosphate, with or without ammonium sulphate The better farmers realize that far higher yields can be expected when potatoes are sown after a pasture stand two or three years old The good effect is due mainly to a big reduction in the number of potato parasites Sowing is followed by the usual cultivation between the rows to conserve moisture and soil nutrients Most farmers "mould" their crops heavily, mainly to combat potato moth (*Phthororimaea operculella*) which during dry seasons is the most destructive potato parasite in this district Moths reach the tubers more easily in heavy soils than in peaty soils because heavy soils crack during dry weather and the funnel shaped hole formed by rotation of the main stalk during windy weather does not readily fill in Losses are said to be more severe among early crops and especially with the variety Carman

However, even with the utmost care in preparation and subsequent cultivation, the yield depends primarily on the occurrence of rain and the absence of frost Soaking rains are especially necessary at flowering time, plants can suffer severe damage or even death from summer frosts (see p 98)

Maize for grain and Sweetcorn These two crops are very similar as to seeding, manuring and cultivation Usually 8 12 lb per acre of seed are sown with a corn planter so that the crop can be cultivated in two directions Superphosphate is usually applied at the rate of 1 to 2 cwt per acre, and farmers say that even this is not necessary if maize follows a heavily supered potato crop Strict weed control is essential The average yield of maize grain for county Mornington varies from 7 7 to 33 3 bushels per acre The Victorian average yield over the same period is 33 8 bushels per acre which suggests that except for abnormal years, this district as a whole is too dry for really good yields though some areas may be favoured with ground water accessible to the roots Proximity to the canneries justifies the risk of failure with sweetcorn Frost can be very serious especially while the styles are extruded for fertilization Except in very unfavourable seasons when many crops are fed to stock in the same way as ordinary drilled maize, the cobs are picked at maturity and stored in cribs, or in the case of sweetcorn, picked some time before maturity and sent straight to the cannery In this district, stover is normally worth about £1 an acre as stock feed

Asparagus Three of the six main Victorian asparagus farms are in this district Each of the three grows over 100 acres under contract to canneries

Seed selected by the cannery is sown in rows 6 feet apart, and after a year seedlings are transplanted at a depth of about 6 inches in rows of 4 feet to 6 feet apart Growers usually apply ½ to 1 ton per acre of manure (mainly superphosphate) The stand is ready to cut when three years old and growers find that tips do not begin to deteriorate for about fifteen years The tips are cut daily from October to December

Cutting is stopped during December so that the tops make sufficiently vigorous growth to replenish the food store of the rhizomes, canneries have to be free at this time to deal with other vegetables and soft fruits

Asparagus beds are cultivated throughout the growing period to keep them weed free and the crowns well covered with soil During winter the tops die and are cut off Weed control is not essential and stock can be turned in to graze the volunteer growth

Green Peas Usually 5 bushels per acre of seed are sown with a dressing of about 3 cwt of superphosphate Where peas are grown under contract to a cannery, the whole plants are cut with a mower, loaded on to a motor truck and taken to the factory where the peas are automatically shelled, processed, and canned Selected areas are allowed to mature and the seed used for next season s crop

Other Cash Crops The areas of the remaining cash crops are unimportant, however the recent stimulus to the flax industry has resulted in the decision to erect a flax mill at Koo-wee-rup Those farmers who have decided to grow flax are given access to expert advice and what is very important a guaranteed price Nearly a thousand acres were sown in 1940 41

"DAIRY WITH CASH CROP FARMERS

There are 66 farmers deriving their income from these two activities combined and the general discussions on dairying and cash cropping apply equally to these men The proportion of small, medium and large herds among these farms is practically identical with that of dairy farms A crop pasture rotation is beneficial from the stand-point of cash cropping but apart from the small amount of feed obtained from crop refuse and cropland weeds, the stock management of this type of mixed farm only differs from that of pure dairying in the smaller total pasture area available Much of the district is undoubtedly suited to cash crops and many farmers will probably begin to grow them again should prices become reasonably stable

The average mixed "dairy-with-cash-crop" farm is, at present one of 89 acres fourteen of which are annually sown to cash crop, it carries 22 milking cows and also fourteen other stock units The relative importance of potatoes and maize for grain is given on Table VI

TABLE VI.—THE RELATIVE IMPORTANCE OF MAIZE FOR GRAIN AND POTATOES ON "DAIRY WITH CASH CROP" FARMS

—	Maize for Grain.	Potatoes.	Other Cash Crops.
Total area of crop . . .	378	388	119
Average area grown per farm ..	12	9	9
Number of growers .	31	41	13
Percentage of total "dairy with cash-crop" farmers	47	63	20

Of the twenty farmers growing two of these crops, eleven grow potatoes and maize. "Other cash crops" include sweetcorn, onions and other vegetable crops.

MINOR OCCUPATIONS.

The four remaining agricultural activities may be dealt with summarily, because it is almost certain that if maximum farm income had to be realized, dairying would replace all forms of production other than cash cropping.

Cash-crop with other Stock. This is a group of ten cash-crop farmers who, in general, have large holdings and quite a lot of stock other than dairy cows. The average farm is one of 250 acres with 55 stock units and 52 acres of cash crops, 23 acres of which are potatoes or maize for grain while the rest is asparagus, sweetcorn or other vegetables. The stock consist mainly of sheep, but some farmers have quite large numbers of beef cattle Among the eight men with sheep, the average flock is of 270 mature sheep and 130 lambs. Nearly all topdress a small proportion of their pastures and manure their cash crops at approximately the same rate as do the cash crop farmers.

Sheep Farmers: The nine farmers who derive the whole of their income from sheep have, on an average, a farm area of 195 acres and had a flock of 460 sheep with 145 lambs at the date when records were collected. Of the six men who topdress their pastures, only two topdress more than half their farm.

Intestinal parasites and footrot are usually troublesome and good farmers drench their lambs as often as once every three weeks and control the spread of footrot by strict quarantining of affected stock and by rotational grazing.

However, the sample of farmers is so small that nothing else can be said of their systems of management in general except that some fatten store sheep or lambs and others breed their own stock.

Sheep and Dairying: On seven farms sheep and dairying are combined as the main activity. These farms have an average size of 330 acres and are lightly stocked. Herds vary from 11 to 100 cows, the average herd being one of 30 cows. The average flock of 250 mature sheep yields from 7½ to 9 lb. of wool per sheep, and four of these men supplement their incomes with an average

of 60 lambs. The proportion of their land topdressed and sown to green fodder crops is roughly the same as that for pure dairymen.

Miscellaneous Graziers: There are fifteen farmers whose farming activities cannot be classified under any of the preceding categories. Five of the farms have more than a quarter of their area uncleared. Four men run sheep as well as beef cattle, calves or heifers while the others run beef cattle, heifers or horses. Supplementary green fodder is not generally grown, but top dressing is nearly as popular as with dairymen

VI. Physical and Chemical Analysis of Soil Types.

MECHANICAL ANALYSES.

Representative samples of the main soil types were separated into the mechanical fractions defined by the "International" limits, viz., coarse sand 2·0 to 0·2 mm., fine sand ·2 to ·02 mm., silt 0·2 to 0·002 mm., and clay less than 0·002 mm. Percentages, calculated on an oven-dry basis, are set out in Tables VII. and VIII.

TABLE VII.—MECHANICAL ANALYSES OF KOO-WEE-RUP PEATY CLAY AND DALMORE CLAY.

Soil Number .	K 06.			K 12.		
Soil Type . ..	Koo-wee-rup Peaty Clay.			Dalmore Clay.		
Horizon . .	a	b	c.	a	b	c
Depth (inches) .	0–9	9–17	17–33	0–9	9–34	34–44
Coarse sand	8·2	24·1	27·6	2·7	2·0	21·3
Fine sand . .	11·5	21·2	16·2	8·5	3·8	24·6
Silt ..	14·5	15·7	15·0	12·1	6·3	20·6
Clay	46·1	36·6	41·4	60·9	82·0	33·4
Carbon . ..	10·2	2·9	1·0	7·9	3·8	1·2
Nitrogen . ..	·68	·14		·43	·23	
pH	4·9	5·1	5·0	5·1	5·3	5·4

TABLE VIII.—MECHANICAL ANALYSES OF SWAMP FRINGE TYPE AND OF A PODZOL ON GRANITE

Soil Number ..	K 25.			K 31		
Soil Type	Swamp Fringe Type.			Podzol on Granite.		
Horizon	a.	b.	c	a.	b	c.
Depth (inches) ..	0–10	10–16	16–36	0–4	4–13	13–30
Coarse sand ..	3·3	4·0	2·4	48·0	43·9	15·3
Fine sand	48·4	44·5	37·0	23·8	25·8	10·0
Silt	22·4	22·0	21·2	13·6	15·4	4·7
Clay	22·6	27·3	37·6	8·0	10·0	70·0
Carbon .. .	2·6	1·3	1·0	3·9	0·6	..
Nitrogen	·16	..	..	..	..	..
pH	5·4	5·4	5·3	..	..	..

The main characters of texture are shown in the tables—viz, the clayey texture of the surface and the gritty subsoil of both Koo-wee-rup peaty clay and Dalmore clay, and the silty nature of the swamp fringe type. Analyses of other surface samples of Koo-wee-rup peaty clay and swamp fringe type confirm the generally representative nature of these profiles; yet it must be borne in mind that a few small areas have been mapped as either of these major types when, in fact, their percentage of sand may exceed that of the type by as much as 25 per cent. owing to the proximity of sandy areas Likewise, although there is generally less than one per cent gravel in Horizon 1 of Koo-wee-rup peaty clay, some exceptional samples contain as much as 10 per cent.

The mineral fraction of Dalmore clay varies remarkably little.

HYDROCHLORIC ACID EXTRACT.

Representative soils were extracted with boiling hydrochloric acid (as in the International method). Potassium and phosphorus were estimated and the results conventionally set out in Table IX. as percentage K_2O and P_2O_5 respectively. Although the number of samples is small, certain general relations are indicated.

TABLE IX.—POTASSIUM AND PHOSPHORUS DISSOLVED BY BOILING HYDROCHLORIC ACID.

Soil Type.	Sample Number	Depth (Inches)	K_2O (Per Cent.)	P_2O_5 (Per Cent.)
Dalmore Clay	K 12a K 12b	0– 9 9–34	·32 ·27	·164 ·030
	K 13a	0–10	·28	·124
Koo-wee-rup Peaty Clay	K 06a K 06b	0– 9 9–17	·20 ·11	·150 ·025
	K 01a	0–10	·19	·158

The reserve of potassium is moderately good Weathered felspar is a common constituent of the sand fraction and its potassium (which is not extracted by this method) makes the total reserve still higher. Sample K13a is a virgin Dalmore soil; K01a is a virgin burnt peat. They show no appreciable differences from cropped land; neither is there any difference between the burnt K01a and the unburnt K06a.

There is no significant difference between the HCl-soluble phosphorus of the swamp types; but it is remarkably high when compared with the 0·05 per cent. or less of P_2O_5 which is typical of the nearby districts of Berwick and Pakenham. Phosphorus appears to be concentrated in the surface horizon. A report by Teakle (8) on the peat soils and related soils of Western Australia, includes many analyses of surface and subsoil HCl-soluble phosphorus which almost invariably show the same feature of surface concentration.

ORGANIC MATTER.

The organic matter was estimated by Tiurin's rapid approximate method (using the figure 1 ml. normal oxidizing agent equals 3·3 mg. carbon) and multiplying carbon by 1·72 to calculate organic matter.

Dalmore clay is consistently high in organic matter.

Koo-wee-rup peaty clay generally has over 15 per cent. organic matter but the figures for the badly burnt phase and for the transition phases are naturally lower. The range of organic contents is a good indication of how much the peaty type varies in colour and texture. Both burnt and unburnt samples of Koo-wee-rup peaty clay may contain less than 15 per cent. of organic matter. Of these, the burnt soils are often reddish-brown ash, the depth of colour being mainly determined by organic content; the unburnt soils may be sandy, or if not are grey and somewhat cloddy. Those soils with over 15 per cent. organic matter are generally dark grey and very friable, yet may contain enough ash to impart a red tinge.

TABLE X.—ORGANIC CONTENT OF SURFACE SOILS (TIURIN'S METHOD)

Soil Type.	Number of Samples	Mean (Per Cent.)	Distribution of Samples.				
			5–9 Per Cent	10–14 Per Cent	15–19 Per Cent	20–24 Per Cent.	>25 Per Cent
Koo-wee-rup Peaty Clay	15	15·0	1	5	6	2	1
Dalmore Clay	4	13·5		2	2		.
Swamp Fringe .	3	7·7	3	.			

The Swamp fringe type contains less than 10 per cent. organic matter, subsoils of all the swamp types contain less than 5 per cent. except where raw peat occurs.

Total nitrogen was determined by Kjeldahl's method. The results given in Tables VII. and VIII. go to show how large is the nitrogen reserve of the highly organic swamp types. The C/N ratio is quite favourable for the decomposition of organic matter and the production of nitrate. Raw peat from Catani (containing nearly 45 per cent. organic matter) has a ratio of 22 : 1 compared with the ration of 15 : 1 to 20 · 1 on normal swamp soils.

pH VALUES.

The soil reaction was determined by means of the glass electrode using two parts by weight of soil to three of water. The figures for fifteen unburnt surface samples of swamp types are remarkably constant, ranging from 4·8 to 5·4: eleven lie within the range of 5·0 to 5·2. Burnt soils have a consistently higher

reaction, the average being 5·6. Otherwise there is no significantly different reaction between swamp types; nor is there a significantly different reaction between surface and subsoil horizons. The acidic character of Koo-wee-rup soils is not at all abnormal when compared with the usual mineral soils found in the neighbouring districts of Berwick and Pakenham.

READILY AVAILABLE PHOSPHORUS.

Readily available phosphorus was extracted from the soil with a large excess of 0·002N H_2SO_4 and estimated by Truog's modification of the Deniges colorimetric method. Truog (10) says that, if readily available phosphorus approaches or exceeds 45 parts per million (p.p.m.), it may be concluded that the soil is sufficiently well supplied with phosphorus to produce good crops of cereals and legumes although 75 p.p.m. or more is desirable for most cash crops. However, if the amount extracted falls below 10 p.p.m. it is certain that there is insufficient readily available phosphorus in the soil to produce satisfactory crops.

TABLE XI.—READILY AVAILABLE PHOSPHORUS CONTENT OF SURFACE SOILS (TRUOG'S METHOD)

Soil Type	Number of Samples	Mean (p.p.m.)	Distribution of Samples (Pts/Million)		
			0–10	11–25.	26–45
Koo-wee-rup Peaty Clay ..	14	16	5	8	1
Dalmore Clay . ..	4	26		2	2
Swamp Fringe	3	9	2	1	..

Table XI. shows that on this basis all soils of the district which were examined are low in readily available phosphorus. Dalmore soils are relatively rich and swamp fringe soils relatively poor. Analyses were made of virgin soils from both Dalmore and Koo-wee-rup types, and results, viz., 13 and 3 p.p.m. respectively, were so low as to suggest that all results in Table XI. essentially measure the cumulative effect of applications of phosphatic fertilizer. Subsoils contain extremely small amounts of readily available phosphorus.

EXCHANGEABLE CATIONS.

(1) *Calcium, Magnesium, Sodium, Potassium.*—The four main metallic cations extracted by leaching with normal ammonium acetate at pH 7 are recorded in Table XII. Their relative importance is quite typical of the soils of southern Victoria. Calcium and magnesium predominate in the surface horizon with magnesium becoming increasingly important in the subsoil. Sodium is rather high in one peaty sample, owing to the proximity of the sea. The figure for exchangeable potassium gives useful information as to the amount of available potassium.

The analyses indicate that Koo-wee-rup soils are well supplied with available potassium, due no doubt to its constant replenishment from the breakdown of primary minerals.

TABLE XII.—EXCHANGEABLE CATIONS (OTHER THAN HYDROGEN) IN SOILS LEACHED WITH AMMONIUM ACETATE.

Soil Type.	Sample Number	Depth (In.)	Exchangeable Cations. Percentage of Total: Ca.	Mg	Na	K	Total in Milli Equiv per 100 gm Ovendry Soil	pH	Percentage Clay	Percentage Organic Matter
Dalmore Clay ..	K 12a	0–9	49	36	2	13	37·2	5·1	66·9	14
	K 12b	9–34	31	58	8	3	29·6	5·3	82·0	6
	K 12c	34–44	29	57	11	3	10·4	5·4	83·4	2
Koo-wee-rup Peaty Clay	K 033a	0–10	52	42	2	4	13·0	5·1		..
	K 06a	0–9	51	38	7	4	16·3	4·9	46·1	18
	K 06b	9–17	35	53	10	2	10·1	5·1	36·6	5
	K 06c	17–33	23	65	9	3	10·8	5·0	41·4	2

(2) *Hydrogen and its relation to the metallic cations.*—Exchangeable hydrogen at pH 7 was determined on a representative set of samples using the p-nitrophenol method of Schofield (7). Total exchange capacity was estimated on the same soils using the rapid approximate method of shaking with excess N/20 HCl and back-titrating the filtrate to pH 7. Exchangeable calcium was estimated directly on this filtrate by precipitation as oxalate at pH 4·0. Results are collected in Table XIII. which shows

TABLE XIII.—EXCHANGEABLE HYDROGEN AT pH 7 COMPARED WITH CALCIUM AND TOTAL EXCHANGE CAPACITY

Soil Type.	Sample Number	Depth (In.)	Exchangeable Ions Milli Equiv per 100 gm Ovendry Soil. Total Capacity at pH 7.	Ca	H.	Ca/H.	Remarks.
Dalmore Clay ..	K 12a	0–9	65	18	28	·64	Well farmed
	K 13a	0–8	.	11*	39	·28	Virgin land
	K 14a	0–8	56*	12*	36	·33	Well farmed
Koo-wee-rup Peaty Clay, normal phase	K 06a	0–9	54	8	40	·20	Normal farm
	K 025a	0–7	53*	8*	42	·19	Normal farm
Koo-wee-rup Peaty Clay, burnt phase	K 01a	0–10	.	6*	13	·46	Normal farm
	K 081a	0–8	27*	9*	14	·64	Limed
Peaty Loam over Sand	K 020a	0–8	19*	4*	15	·24	Very sandy, sand 65 per cent
Swamp fringe ..	K 21a	0–7	29*	7*	21	·33	Normal farm

* Rapid approximate estimation.

that the approximate values agree well with the accurate figures of the Table The consistently low Ca/H ratio is quite in keeping with the low pH in fact the lime theoretically required to bring the surface 8 inches to neutrality ranges from 10 tons per acre on K06a and K025a to 3½ tons on the burnt soils K01a and K031a The burnt peaty soils always have a lower cation exchange capacity and a higher pH than the neighbouring unburnt soil

Although the pH is low and the exchangeable calcium (except on Dalmore types) is only moderate there is no evidence that lime is needed The healthy growth of red clover on many areas gives, in fact, substantial evidence to the contrary But the possibility remains that some of the most acidic soils (those of pH 4 8) may be found to respond to lime This district contains only very small patches of such soil and most of the economic plants (maize, oats potatoes subterranean clover, white clover, and rye grass) are quite tolerant of pH values down to 5 0

General Discussion.

Black swamp soils enjoy great prestige largely because of the impressive luxuriance of natural swamp vegetation and also because the dark colour of many mineral soils is associated with the idea of fertility But, although river flats are certainly more fertile than the surrounding hills this observation cannot be generalized to include peaty swamps

The peaty Koo wee rup Swamp shared the prestige of river flats However the properties of peaty soils vary greatly according to the source of the organic material Probably much of the opposition to its reclamation came from men who knew the poverty of many Irish bog soils

The main dividing line is drawn between —(1) "Lowmoor" peats which are developed in lakes, and are derived from reeds and associated plants and (2) ' Highmoor" peats which in Europe commonly develop on top of lowmoor peat and are usually derived from sphagnum moss The former peats to which this swamp belongs, are far more fertile than the latter which are not only highly acid (pH below 5) but physically undesirable Koo-wee-rup peat, although lowmoor in origin, is rather poorly endowed with calcium, and its pH of 5, though not exceptionally acidic, is more so than are many other lowmoor peats Its supply of readily available phosphorus is inadequate for intensive agriculture However this is a common feature among peats, and a characteristic of most soils of southern Australia On the other hand, the C N ratio has the favourable low value expected of good lowmoor peats and there is evidently a good production of available nitrogen Plant remains quickly decompose and lose their identity in the cultivated zone Also the reserve of potassium

is remarkably large for a peaty soil, a character which is undoubtedly due to the felspathic fraction of the sediments derived from granite. The Koo-wee-rup peat may well be described as "fair average quality".

The peat has disappeared with striking rapidity. Fibrous peat which was often more than 6 feet deep, has after 40 years of agriculture, been mostly, reduced to 8 inches or so of peaty clay or else to a bed of ashes. Less than 10 per cent of the original deep peaty area still contains raw peat. Losses of a similar magnitude have occurred over most reclaimed peat lands of the world, and have in many cases caused problems of drainage and productivity which are far more serious than those of Koo-wee-rup. The famous fens of Lincolnshire, in England, which still produce prolific crops, are known to have shrunk many feet since their reclamation Investigators (11) have studied in detail the subsidence of the widespread peats of the Everglades of Florida and of the Sacramento-San Joaquin delta in California The chief causes of subsidence in these areas are —

(1) Compaction by implements and animals.
(2) Shrinkage due to drying.
(3) Burning
(4) Windblowing.
(5) Oxidation.

The Californian surveys were carried out for fourteen years and showed an average annual subsidence of 2 inches, one half of which was due to burning. The experimental area had been previously cultivated for twenty years, so that compaction and shrinkage were negligible over the period of survey. Windblowing and oxidation therefore account for a loss of 1 inch per annum.

During the first few years after cultivation the virgin Koo-wee-rup peat probably lost over half its volume through compaction and drying. Also, strong winds have undoubtedly removed a considerable amount of dry soil from cultivated paddocks. For example, the gale of 13th and 14th December, 1938, is said to have removed almost a foot of soil from certain areas.

Burning has caused the greatest loss of peat in the Koo-wee-rup district. A shallow burn usually shows an immediate profit because it liberates plant foods and destroys crop parasites; but many fires burnt all the peat leaving a bed of ashes which would not grow satisfactory crops. The ill effects appear to be due to two factors. Firstly, the ash has a low water-holding capacity because the organic colloids are destroyed and much of the clay is baked to form coarser aggregates; secondly, there is no source of nitrogen in the ash. Fortunately, most of the burnt land consists of 8 to 12 inches of ash underlain by a reasonably fertile organic clay loam which can be plowed up and mixed with the

ash to ameliorate both of these faults. The nitrogen level can be further raised by the continued use of clovers. A few small patches of land on which the porous ash bed is as much as 2 feet thick will always suffer badly from dryness. A shallow ashbed is not altogether undesirable. It has a consistently higher pH than the unburnt soil, which may be a good thing; it will also have a permanently friable texture, whereas the unburnt soil is in danger of becoming cloddy.

Some farmers have, in fact, noticed that continually cultivated paddocks of peaty soil have already become quite cloddy. This is the result of cultivation accelerating the oxidation of organic matter. The normal equilibrium for a well-drained clay under pasture in this climate is certainly no more than 10 per cent. organic matter but may be as low as 6 per cent. under intensive cultivation It is impossible to estimate how long it will take for peaty soils to reach this equilibrium because of their variability in depth and present organic content and because of the factor of management; besides which, the rate of depletion will decrease as equilibrium is approached.

The dairyman or grazier on Koo-wee-rup peaty clay really has nothing to fear from this change, because a denser texture implies a greater supply of soil moisture for summer pastures, and oxidation causes no loss of mineral nutrients from the soil; and the present generation of cash crop farmers has but little cause for pessimism because they can maintain quite a good texture by the use of approved pasture rotations; but the soil may deteriorate with unpleasant rapidity under continual cultivation

Dalmore soil is inherently richer in exchangeable cations than other swamp soils; its pH is the same Although highly organic it has always been a mineral, not a peaty soil. The Dalmore farmer can expect a similar deterioration in texture as organic matter is lost, although drainage will always be reasonably good on the normal phase owing to the buried stratum of peat. Such deterioration would be shown by an increasingly narrow range of moisture contents over which the soil can be satisfactorily worked The change will naturally be slow, but the non-peaty phase which was originally not so richly endowed with organic matter has already presented this difficulty to cultivation. As before, pasture rotations slow down the change and prevent the ultimate formation of an unworkable soil.

Relation of Carrying Capacity to Soil Type.

As in many other dairying districts of fairly generous rainfall, carrying capacity depends to a far greater extent on management than on soil. There is no evidence of any significant difference between the carrying capacity of the swamp soils, other than the sandy type; this requires a very efficient system of improvement and management in order to realize its potential carrying

capacity which appears to be a little less than other swamp types The podzolic soils are as yet mostly undeveloped although similar types near Berwick are now carrying stock at the rate of one cow to two acres

The black land of Dalmore is the only part of the district which gives the visitor an impression of prosperity The general impression that conditions are far from prosperous over much of the district is borne out by the fact that a large proportion of farmers in the district have come under the farmers debt adjustment scheme This proportion varies with the size of farm rising from 15 per cent of the farms below 40 acres to a maximum of 31 per cent in the group between 91 and 120 acres This maximum among the larger farms is surprising and may well be due to bigger proportional losses in potato growing

Land values have fallen to almost half their peak levels reached during the potato boom of the late twenties nowadays Koo wee rup soils commonly change hands at about £30 an acre the inherently more fertile Dalmore soils at about £40 an acre Apart from past troubles it seems reasonable to expect under present economic conditions modest prosperity on farms as small as 60 acres because the land has a potential carrying capacity of at least one cow to two acres

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ART. VII.—*Ecological Studies in Victoria.—Part VI.—Salt Marsh*

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Salt Marshes exist at several points along the coast, but at Western Port there is a very strong development at the northern and north-western portions, with Mangrove on the seaward side. These marshes are not regularly washed by the tide, but only occasionally, by exceptionally high seas. During the summer the evaporation of water is high and glistening salt may be seen on the landward side. At this period, therefore, the concentration of the soil solution is greatest and this is the outstanding factor of the environment. The Mangrove, *Avicennia officinalis*, in contrast to the marsh, is right in the tidal water and twice each day its breathing roots are exposed to the air. The Mangrove marks the limit of the high tides. The junction between the Mangrove and the Salt Marsh is sharp, particularly where the fall away from the latter is well marked, as at Tooradin pier. Where the slope is very gradual the junction is not so well defined. This is seen at Bembroke and Hastings. However, in this latter case there is not a general mixing of the marsh flora with the Mangrove, but chiefly with *Salicornia australis*. Where the transition is gradual, some of the marsh plants are regularly covered by the tide, but the depth of water is not great. Although there is a transition zone in some cases, the true salt marsh community finishes as soon as Mangroves are met with, and in these studies the investigation has not been carried into the tidal zone.

On the landward or inner margin of the salt marsh, there is very frequently a narrow zone, devoid of shrub growth and often quite bare, on which in summer, salt is clearly visible. The bare areas of the zone have somewhat the appearance of the clay pans of the warmer parts of Australia. In parts, this zone is vegetated by *Mesembrianthemum australe*, and in others appears to have been formerly occupied by this plant. The reason for its death is not known. This zone is never broad and where present it is succeeded by the Swamp Ti-tree, *Melaleuca ericifolia*, association. This latter where present marks the landward limit of the salt marsh, whether the narrow Mesembrianthemum zone be present or not. The Swamp Ti-Tree is essentially a fresh water plant although it endures brackish water. At the northern end of Western Port the ti-tree formerly extended to the main Gippsland

Railway, approximately ten miles away. Along the north-west of Western Port the ti-tree occupies only a few feet between the marsh and sand hills These sand hills might be regarded as dunes but although abutting on the sea, the flora is not that of the coast dunes. They bear instead typical heath vegetation dominated by Manna Gum, *Eucalyptus viminalis.*

PHYSIOGNOMY AND COMPOSITION

The salt marsh is essentially a shrub community since the dominant plant *Arthrocnemum halocnemoides* is woody, amply branched and stands some three feet high In this shrub the ultimate branchlets have a succulent cortex which withers as growth proceeds, leaving the woody axis unimpaired for conduction and for increase in diameter These bushes do not form a closed canopy and between and beneath them lies the main portion of the vegetation. This latter consists of perennials which are also mostly succulent, but which more or less die down in the late autumn Before doing so, *Salicornia australis* assumes a very bright reddish colour Both *Suaeda maritima* and *Mesembrianthemum australe* also become brightly coloured. The lower stratum of vegetation forms a complete or almost complete soil cover and the association is therefore a closed one. *Salicornia australis* forms the major portion of the lower stratum partly because it is taller than the other constituent species but more particularly on account of the profuse branching of its aerial shoots, which if they bend over and reach the ground may root. *Selliera radicans*, which does not produce aerial shoots, but only runners or shallow rhizomes, may rightly be considered as constituting a ground or third stratum; but because it is not universally found and its erect leaves are not shaded by the low-growing species, it can be united with the other members of the second stratum. The effective covering of the soil, thus forming a closed community, is due to the rhizomic or runner habit of the plants of the second stratum, the peaty soil being interwoven with roots and rhizomes In early winter the small rosettes of *Samolus repens* become very evident and appear to be individual plants. This species sends out leafy runners which ultimately root at the apices but not along the length, and form new plants. They also appear to arise from rhizomes The rosettes send up one or more aerial flowering shoots.

COMPOSITION.

Although the salt marsh is densely populated with individuals the species population is small. A small number of species is a characteristic of a pioneer community, as in a fore dune, but there is the added fact that the individuals are widely separated. In such a community there is some outstanding adverse factor of the environment which is reflected in the sparseness of the individuals.

In the marsh, however, while there is a paucity of species, there is also an abundance of individuals which form a complete ground cover. This is somewhat the reverse of the usual conditions. Usually there is an intimate connection between the numbers of individuals present and number of species. This is not always the case, however, and an outstanding exception is that of the Ti-tree association of the Koo-wee-rup Swamp, where the soil is densely covered chiefly by one species. The salt marsh association provides another exception in regard to its floral composition for, one family, Chenopodiaceae, dominates it both structurally and systematically. This family is represented by four genera, each with a single species In addition to the two very commonly occurring species, *Salicornia australis* and *Arthrocnemum halocnemoides*, there are *Atriplex paludosum* and *Suaeda maritima*. The genus Atriplex is represented on the coast by another species *A. cinereum*, which is perhaps best regarded as a strand plant It has several species in the Mallee. *Atriplex paludosum* occurs only sparsely in the marsh and in four transects at widely separated places, this species did not occur in a single quadrat. *Suaeda maritima* is also sparse in the marsh itself but it occurs particularly where there is any sand and mostly towards the margins.

A striking feature of the association is the great lack of connection between its floral composition and those of the adjoining associations. When compared with the equally maritime association, the Sand Dune, there is a conspicuous difference. The dune flora does reflect the characteristic flora of the State since there occur the genera Casuarina, Leptospermum, Acacia, Banksia, and Olearia. All of these genera occur in the heathlands as well and in other associations, but not one has a representative in the marsh. On the other hand, the genera of the marsh, even species, are distinctly cosmopolitan. The genera Suaeda, Salicornia, Statice, Frankenia and Samolus are equally at home in European salt marshes as in Victoria.

The genera Glyceria, Juncus and Atriplex are represented both in dry land associations of the State and in the salt marshes of Europe. The species *Suaeda maritima* and *Juncus maritimus* are found both in our own salt marshes and those of Europe The affinity, therefore, of the salt marsh is extra-Australian, while the two adjoining associations, Heath and Dune, are intensely Australian.

Along the landward margin of the marsh, occur a number of plants which swell the total number of species but which are not found, or only sporadically, in the marsh itself. These are listed as marginal in the table of species found in the Salt Marsh at Western Port (Table 1).

Of the families given in Table I. only one, Goodeniaceae, is characteristically Australian. This family is also represented on the coastal dunes but by a different genus.

TABLE I.—COMPOSITION OF SALT MARSH.

Juncaginaceae	*Triglochin striata*	o.
	T. minutissima	m.
Gramineae	*Distichlis spicata*	o.
	Glyceria stricta	o.
	Stipa teretifolia	o.
	Sporobolus virginicus	m.
	Lepturus incurvatus	o.
Cyperaceae	*Cladium filum*	f.
Juncaceae	*Juncus maritimus*	l.a.
Chenopodiaceae	*Atriplex paludosum*	o.
	Suaeda maritima	o.
	Salicornia australis	v.c.
	Arthrocnemum halocnemoides	v.c.
Amarantaceae	*Hemichroa pentandra*	c.
Aizoaceae	*Mesembrianthemum australe*	c.
Caryophyllaceae	*Spergularia rubra*	m.
Malvaceae	*Plagianthus spicatus*	m.
Frankeniaceae	*Frankenia pauciflora*	f.
Umbelliferae	*Apium australe*	v.r.
Primulaceae	*Samolus repens*	c.
Plumbaginaceae	*Statice australis*	o.
Gentianaceae	*Sebaea albidiflora*	m.r.
Convolvulaceae	*Wilsonia humilis*	r, la.
	W. Backhousei	o, la.
Goodeniaceae	*Selliera radicans*	c
Compositae	*Brachycome graminea*	m.r

c = common; f = frequent; l.a. = locally abundant, m = marginal; o = occasional
r = rare; v.c. = very common; v.r. = very rare

Only two of the genera have more than one species, while two families have more than one genus. It has been pointed out in previous papers of this series that one of the characteristics of an association is that the average number of genera per family always exceeds the number of species per genus. The values here are 1·4 and 1·1 respectively. Generic characters are not in general related to, or affected by the environment, hence there is theoretically, at all events, no barrier to the entry of any particular genus. A species on the other hand must be adapted to the particular environment or it cannot survive. Quite commonly the specific characters are an expression of the physiological adaptation to the environment. This, however, is not always the case, as is seen in grasses of the Marsh.

The frequencies of the marsh species, omitting the marginal ones, is expressed in Table II., which gives the percentage occurrences in 60 quadrats taken across the marsh, from the Ti-tree to the Mangrove, at three widely separated places. The quadrats were one square yard, distant sixteen feet from one another.

While the percentage frequencies give a measure of the occurrence of the species they do not necessarily convey any information regarding their distribution. The low frequencies of

TABLE II.—FREQUENCIES OF SPECIES IN SALT MARSH.

Species.	Percentage Occurrence.
Salicornia australis	87
Arthrocnemum halocnemoides	70
Samolus repens	63
Hemichroa pentandra	63
Distichlis spicata	28
Selliera radicans	25
Triglochin striata	18
Wilsonia Backhousei	15
Juncus maritimus	12
Cladium filum	10
Suaeda maritima	5
Mesembrianthemum australe	5
Stipa teretifolia	3
Statice australis	2

both *Mesembrianthemum australe* and *Statice australis* are due to different causes. The former is restricted to the landward side of the marsh and hence can only occur in quadrats taken on the edge. This species, therefore, will almost always occur in a transect. On the other hand *Statice australis* is sporadically distributed over the marsh and its low frequency is a measure of its sparse distribution. *Atriplex paludosum* is similarly distributed, but it did not occur in any of the quadrats Both of these species occur as isolated plants, while other species, as *Selliera radicans*, form large colonies, due to their rhizomic habit. The high value for *Salicornia australis* is due to its universal distribution. It has a greater amplitude as regards the concentration of salt than any other species, for it passes from the fairly uniform concentration at the Mangrove margin, across the marsh, and into the ti-tree community for a short distance. *Mesembrianthemum australe*, which commences in the partially bare zone, associates with *Salicornia australis* for a short distance, but passes inland, far removed from salt influences, along with the ti-tree.

To the east of Tooradin where the Toomuc and Cardinia Creeks enter the bay, the marsh ends on its landward side in grassland. Here *Arthrocnemum halocnemoides* again may be regarded as marking the limit of the marsh, but the boundary is poorly defined. *Mesembrianthemum australe* here is much more common and extends well into the marsh. This is somewhat surprising for here the dominating shrub stratum is better developed, taller and closer together, thus casting a greater shade. There is beyond the marsh proper, as limited by the shrub stratum, a transition zone in which *Distichlis spicata, Salicornia australis* and *Mesembrianthemum australe* densely intermix and form a complete ground cover.

Environment

It frequently happens that in an association one factor of the environment is so pronounced as to dominate all others In the salt marsh the outstanding factor is the highly concentrated soil solution compared with that usually found Climate has but secondary effects Wind which is the cause of the moving sand in the coastal dunes here is the force bringing the high seas over the marsh Temperature also has a secondary effect in assisting evaporation in the summer period and thus concentrating the soil solution As shown in Table III there is no dearth of water which has been derived at least partly from the sea and rainfall therefore does not necessarily contribute to the needs of the plants The same climatic conditions are being experienced by the other maritime associations, and so the differences between these plant communities cannot be ascribed to any climatic factor The differences lie wholly in the soil This is shown in Table III The soil samples were collected in February during dry weather and when the salt was freely showing along the landward margin The first sample was taken at the junction of the Swamp Ti tree and the Marsh, and the last sample where the Mangrove commenced It will be noticed that although little rain had fallen for some time the water content of the soil was high right across the marsh This is in striking contrast to the moisture content of other associations under similar climatic conditions at the same period of the year (Patton 4, 5) The variation in the moisture content calculated on the dry weight from 421 per cent to 92 per cent is due chiefly to the high and variable organic content of the soil Since the chief constituent of the mineral soil is clay, the combination of clay and organic matter gives a high water holding capacity Added to this, however is the fact that the

TABLE III—SOIL SAMPLES FROM TOORADIN SALT MARSH

Distance in Feet	Moisture Content per cent	Loss on Ignition per cent	Gms of NaCl in 100 gms		Equivalent O P in Atmos	Remarks
			Of Dry Soil	Of Soil Moisture		
0	92	44 3	4 000	4 35	30 8	Edge of Ti Tree Mesembrianthemum
35	329	70 4	24 925	7 58	53 6	Arthrocnemum and Salicornia
86	268	36 6	18 100	6 75	47 6	Salicornia
141	421	62 5	22 425	5 33	37 7	Salicornia and Hemichroa
197	170	27 6	8 175	4 81	33 9	Salicornia and Hemichroa
255	173	25 7	9 450	5 46	38 6	Arthrocnemum and Samolus
317	116	14 7	5 575	4 81	33 9	Salicornia Samolus Arthrocnemum Sellera
385	180	26 0	6 775	3 76	26 6	Salicornia and Samolus
426	102	10 5	4 375	4 29	30 4	Commencement of Mangrove

area is flat and drainage is bad. In places there may be no, or almost no, mineral soil at all, the whole upper part consisting of peat. In this series of papers soil is defined as the medium in which roots find themselves, no matter what that medium may be. The definition is wide, but for ecological purposes it works well.

The chloride content of the soil, ascertained by titration against silver nitrate, has been expressed, in this and later tables, as sodium chloride. It will be noted that where the ignition loss is high, both the water and the salt content, calculated to dry weight, are also high. This is merely an expression of the fact that the greater the amount of peat, the greater amount of salt water present. The actual variation of the concentration of the soil solution, however, is not wide, as is shown by the amount of salt in 100 gms. of soil moisture In the last column the corresponding osmotic pressures for the concentrations are given In Table IV. are given the results of portion of another traverse at an area where the Mesembrianthemum zone on the inner or landward margin of the marsh was well developed. This zone bears mesembrianthemum in parts while other parts are bare. A sample of the soil from the ti-tree community was also collected

TABLE IV—ANALYSIS OF SOIL, SALT MARSH, TOORADIN.

Distance in Feet.	Moisture Content per cent.	Loss on Ignition per cent.	Gms. of NaCl in 100 gms.		Equivalent O P in Atmos	Remarks.
			Of Dry Soil	Of Soil Moisture.		
−8	41·29	25·38	·824	1·995	14·1	Ti-Tree
0	129·79	53·19	3·708	2·857	20·2	Edge of Ti-Tree
16	75·30	43·09	6·735	8·944	63·2	Getting bare Mesembrianthemum
48	60·78	41·62	11·370	18·707	132·2	Quite bare
80	209·08	63·00	15·347	7·340	51·9	True Marsh Arthrocnemum and Salicornia
112	310·91	59·51	19·158	6·162	43·6	

The high salt concentration and consequently high osmotic pressure of the bare areas is apparently the reason for the absence of vegetation. Yet these have been vegetated at least in part, for the soil, as the loss on ignition shows, contains a high percentage of organic matter and the remains of dead plants, in situ, can be seen. Both Tables III. and IV. indicate that the greatest concentration of salt is towards the landward margin, and that there is a decrease towards the sea. Within the marsh itself, the osmotic pressure of the soil with reference to common salt content only, is generally below 50 atmospheres. The concentrations in the marsh soil generally agree with the statement of Braun Blanquet (1) that in the uppermost layers of the Salicornia marshes in the Mediterranean region, the common salt content reaches 8 to 10 per cent. during the summer drought.

The marsh proper commences with the appearance of *Anthrocnemum halocnemoides* and from its first occurrence to the appearance of the Mangrove, the marsh is always moist and the soil contains a high percentage of organic matter. The amount of organic matter and clay in the soil is not uniform, the differences are largely due to very small differences in the elevation of marsh, the lower portions containing more mineral soil while the higher may consist of peat only. The peat may de described as fibrous, for when dried it distinctly has the appearance of a confused mass of threads. When fresh, it is exceedingly difficult to separate on account of the mass of long thick walled root hairs which ramify through it. How much of the peat horizon is living and how much dead it has not been possible to determine.

Halfway across the marsh, where the peat was well developed and where there was a full representation of the commonly occurring species, samples of the soil were taken every three inches from the surface to water level, which was just below twelve inches In Utah, Harris (2) also found that in marsh areas bearing *Salicornia utahensis*, the water level was close to the surface. The top six inches of the marsh at Tooradin were very peaty and had, in addition, abundant living rhizomes and roots. The loss on ignition, therefore, is not a true indication of dead organic content. The living and dead matter almost ceased at six inches. There was a sharp line of demarcation between the peat and the clay soil below in which there were very few living roots. Braun Blanquet (1) remarks that it is easy to remove the upper layer of soil with the roots. The striking differences between these layers is seen in Table V. On account of the wide differences in organic content, the water content of the two upper samples was much higher than the two lower, in spite of the fact that the lowest was immediately above the water table.

TABLE V.—ANALYSIS OF SOIL SAMPLES TAKEN VERTICALLY IN SALT MARSH, TOORADIN.

Depth Inches.	Moisture Content per cent.	Loss on Ignition per cent.	Gms of NaCl in 100 gms		Osmotic Pressure in Atmos.	Remarks.
			Of Dry Soil.	Of Soil Moisture.		
3	345	55·2	20·96	6·07	42·90	Fresh roots and rhizomes
6	347	49·1	21·27	6·13	43·30	Very peaty
9	119	21·8	7·60	6·39	45·20	Few roots
12	99·5	20·4	6·35	6·35	45·10	Dark clay

The results in Table V. indicate that despite wide differences between organic and water content of the samples, the concentrations of salt per 100 gms. of water are very similar. This means that the soil solution is approximately the same vertically through

the soil, due no doubt, to the proximity of the ground water The osmotic pressures corresponding to the common salt concentrations, are all below 50 atmos

The strength of the soil solution is the outstanding feature of the environment and plants if they are to succeed, must have a suction force greater than the osmotic pressure of the soil A series of plants taken over various portions of the marsh, at the same time as the soil samples gave the suction pressures shown in Table VI The method used for determining the suction pressures was by weighing small pieces of tissue before and after immersion in solutions of known concentrations

TABLE VI —SUCTION PRESSURES OF SALT MARSH PLANTS TOORADIN

Species	Suction Pressure
	Atmos
Selliera radicans	51 68
Hemichroa pentandra	47 88
Suaeda maritima	44 84
Salicornia australis	48 70
Mesembryanthemum australe	35 30

With the exception of the last the pressures are comparable to the osmotic pressures of the soil solutions Under the conditions existing when the samples were taken it would appear that the plants were just maintaining themselves It is surprising to note that *Mesembrianthemum australe* had a lower value than the other species in spite of the fact that it grows in the zone of greatest salt concentration Although determinations were made on material of this species gathered at widely separated points, the suction pressures obtained never equalled those of the other species The osmotic pressure of the sap was also very low By Barger's method it was 34 2 and by the Freezing Point Determination, it was 37 0 The sap was extracted from material collected at several places

It is possible that this plant with its exceedingly high water content, does not depend on root activity for its water requirements during the period of high salt concentration in the soil It continues to grow, even if detached at the expense of the moisture stored in the leaves most remote from the growing point If this be the case the water storage is definitely an adaptation which cannot be said of the other succulents

During the winter water lies freely on the marsh, and the concentration of the salt is greatly lessened, as shown in Table VII, but the moisture content does not greatly vary In some cases the results are actually lower than in Table III The samples were collected in June after rain had fallen

TABLE VII.—ANALYSIS OF SALT MARSH SOIL IN WINTER.

Distance in Feet.	Moisture Content per cent	Gms of NaCl in 100 Gms.		Equivalent O P in Atmos.	Remarks
		Of Dry Soil.	Of Soil Moisture		
0	129	·226	·175	1·24	Same as in Table III.
38	374	9·888	2·641	18·69	
86	218	4·340	1·991	14·07	
141	464	8·035	1·732	12·24	
197	167	2·821	1·689	11·94	
255	183	3·255	1·779	12·57	
317	104	1·401	1·347	9·52	
385	168	2·266	1·349	9·53	

Braun Blanquet (1) states that in the Mediterranean areas after the autumn rain the salt may be almost completely leached out. and he quotes 0·15 per cent It is doubtful if such a low figure would be reached on the Western Port Marshes. Even in the summer the water level is close to the surface and this must influence the salt concentration. In winter, when the seas are carried over the marsh, a fairly high concentration would be maintained.

ANATOMY AND PHYSIOLOGY.

Of the four commonly occurring species in the marsh shown in Table II. all are succulent, with the possible exception of *Samolus repens,* whose general appearance is markedly different from the others. Its thin stems and small coriaceous leaves are characteristic of xerophytic plants Succulence is achieved by modifications of different plant organs. In some, as already mentioned, it is the cortex which is the organ of water storage, while in others, as *Mesembrianthemum australe,* the leaves are modified for that purpose Succulents are the true possessors of the marsh, but the fact that non-succulents as *Distichlis spicata* are present is evidence that succulence is not a necessary modification. As, however, the succulents form by far the great majority of the population only these have been studied. The percentage of moisture present in the succulents is given in Table VIII. The moisture content is calculated to the oven-dry weight.

TABLE VIII.—MOISTURE CONTENT OF SPECIES IN SALT MARSH.

Species.	Moisture Content per cent.
Mesembrianthemum australe	1,202
Suaeda maritima	811
Salicornia australis	642
Selliera radicans	610
Hemichroa pentandra	616
Arthrocnemum halocnemoides	495
Samolus repens	358

From the succulents the sap can be readily extracted by pressure and in Table IX are given the chloride contents expressed as common salt of the saps of several species The saps were obtained in quantity from material collected at several places so that they represent average samples The suction pressures given in Table VII are dependent on the concentration of the cell solution and in the marsh plants sodium chloride plays a most important part The concentration of salt in the cell while greater than that of sea water (3) is not as great as in the soil solution The saps of the first and fourth were obtained at the same time as the soil samples given in Table III The remainder were collected after rain had fallen and therefore it is possible that the cell solutions are more dilute than when conditions were drier In addition to the salt content of the cell saps (Table IX) the salt content of the water in the marsh creek is also shown This was collected at the same time as the soil samples of Table III

TABLE IX—SODIUM CHLORIDE CONTENT OF SALT MARSH SAPS AND SALT WATERS

Species	In One Litre of Sap Gms of Cl	In One Litre of Sap Gms of NaCl	O P of NaCl in Atmos
Salicornia australis	39 30	64 76	47 18
Arthrocnemum halocnemoides	5 8	0[illegible]	38 38
Suaeda maritima	[illegible]	44 33	8 80
Mesembrianthemum australe		41 6	27 9
Salicornia radicans	1 [illegible]	34 93	29 60
Creek Water	4	43 51	[illegible]8 27
Sea Water	19 12	31 84	20 67

The sea water given (3) is taken from the ocean where the concentration is said to vary but slightly Along the marsh the concentration varied widely being stronger than the ocean water near the marsh and much more dilute if flood water is coming down the drainage channels *Salicornia australis* which had the highest chloride content 39 30 gms per litre of sap was found by Barger s method to have an osmotic pressure of 47 1 atmospheres by Freezing Point determination 47 5 atmos and by density assuming the sap to be a pure solution of common salt 45 5 atmos In Utah Harris (2) found that in a sample of *Salicornia utahensis* which had an osmotic pressure of 43 9 atmos there was a chloride content of 37 1 gms per litre but the highest pressure 51 9 atmos was associated with a low content of only 25 7 gms of chloride

As an abundance of sap was available the opportunity was taken of comparing the rate of loss by evaporation from the expressed sap and from the plants themselves The leaves of all the succulents have surprisingly thin cuticles when compared

with those of the plants of other maritime associations, the Sand Dune (Patton (5)) and the Mangrove. All these associations are subject to the same climatic conditions. The cuticle of *Samolus repens* is very much thicker than those of the succulents, a character in keeping with the general appearance of this plant. In Table X. are given the thicknesses of the cuticle in microns, together with the number of stomata per sq. mm.

TABLE X—THICKNESS OF CUTICLE AND NUMBER OF STOMATA IN SALT MARSH PLANTS.

Species		Thickness in Microns.	Stomata per sq. mm.
Salicornia australis		4·4	55
Arthrocnemum halocnemoides		5·1	63
Suaeda maritima		5·3	32
Mesembrianthemum australe		5·1	33
Selliera radicans	Upper	5·7	55
	Lower		53
Samolus repens	Upper	9·0	63
	Lower		59

The plants given in Table X. may be grouped into three classes, the first two are leafless, the stomata being on the cladodes, the next two have cylindrical leaves with stomata all round and the last two are flattened, but have stomata on both faces. As the leaves of *Mesembrianthemum australe* had the highest water content, and also a very thin cuticle, it was suitable for experiments on water loss. Its osmotic pressure was close to that of a molar solution of common salt, although its chloride content (Table IX.) was appreciably lower. Experiments with single leaves, which had their bases sealed with a mixture of paraffin wax and vaseline, showed that the ratio of loss per unit area, compared with that from a free surface of water, was 1 : 12·3. When the leaves showed signs of shrivelling the water loss was rapid. Also leaves which were pigmented lost moisture more rapidly than those which were a normal green. Similar results were noted with other pigmented plants. The increased loss is probably due to the fact that the leaves are gradually dying.

As the transpiration from single leaves may be affected by the injury in breaking them off, a large healthy branch was used for comparison with the water loss from three similar containers, one with water, the second with mesembrianthemum sap, and the third with a molar solution of common salt. The branch had nineteen leaves, having an area of 88 sq. cms. All the experimental material was placed in a constant temperature room, the average temperature being 70 degrees F. The ratios of water loss from unit area are given in Table XI.

TABLE XI.—COMPARISON OF WATER LOSS.

Material.	Ratio of Water Loss.
Water	23
Mesembrianthemum sap	20
Salt Solution 1 *N*	19
Mesembrianthemum plant	1

It will be seen that the loss of moisture from the expressed sap does not differ greatly from the loss from pure water, but differs very greatly from that of the plant itself The plant continued to grow for several weeks, the leaves at the base shrivelling in order of age Experiments with shoots of *Suaeda maritima* gave similar results to those of Table XI., which show that the high salt concentration of the sap is not a protection against water loss. It may be noted here that the amount of evaporation varies considerably according to the type of container used, even though they be placed near one another, and the solutions are all at the same depth from the rim

DISCUSSION.

The question whether a halophyte is a xerophyte or not is raised by the habitat in which these plants occur. Since the moisture content of the soil is high and the reservoir beneath is close to the surface, there does not appear to be any necessity for the plant to store water. It is quite possible, as stated by Schimper (6), that the high concentration of the soil solution may make it physiologically dry, which seems to be the case with *Mesembrianthemum australe.* The storage of water in this plant appears to be a provision against lack of supply when the soil concentration is high. Its own moderately low concentration, lower than that of the soil, and its ability to grow without an external water supply, both suggest xerophytism; but any protection against excessive transpiration is not shown save, perhaps, by the low number of stomata per unit area. In the marsh proper, the plants can in no way be considered xerophytes. The soil is always moist and the high concentration of the soil solution is offset by the high concentration of the cell sap. It may therefore be assumed that the plants do not suffer any disadvantage as regards water requirements. That the strength of the soil solution is not an adverse factor may be deduced from the lateness of flowering of the marsh plants, which occurs when the salt concentration in the soil is at or near its maximum. Generally, in Southern Victoria, October is the month of greatest floral activity, but in the marsh the maximum occurs between November and February, while *Statice australis* is not in full flower until April. The small number of species and their apparent lack of

regularity of flowering makes it impossible to determine exactly the period of greatest floral activity Even if it be assumed that the succulents utilize their storage of water for growth flowering and seed production no such explanation can be given for the non succulents particularly *Statice australis* which is vegetatively active in the period of greatest salt concentration and flowers later Although the great majority of the individuals are succulents the presence of plants with a normal morphology as the grasses shows that succulence is not a prerequisite for existing in a Salt Marsh I desire to thank Dr Heyman Chemistry Department University of Melbourne for the Freezing Point Determinations

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ART VIII.—*Studies on Soil Conditions in Relation to Root-rot of Cereals*

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Contents.

In Victoria the effect of mineral nutrition on the severity of eelworm (*Heterodera schachtii* and *Pratylenchus pratensis*) and root rot disease of cereals was first studied in 1936 Small applications of zinc sulphate to Wimmera Black fallow soil were found to promote a marked increase in growth and yield of wheat and oats while the severity of the above diseases was reduced (Millikan 1938) Subsequent investigations have been directed at determining the effects of other minerals on the growth of cereals grown in Wimmera soil and the nature of some of the factors concerned in promoting the responsiveness of the plants to applications of such minerals The significance of these factors in relation to the apparent severity of root rot disease has also been studied The results of this work are set out hereunder

Nutritional Studies with Root-rot Fungi.

While Steinberg (1938), Blank (1939 1941) Foster (1939) and numerous other workers have shown that the need for minute quantities of various heavy metals is a phenomenon widespread amongst fungi generally, there is at present little information available regarding the heavy metal requirements of specific cereal root-rot fungi

Experiments have therefore been conducted to determine whether certain elements which are known to be essential for the growth of higher plants are also essential for the normal development of some of the more common root rot fungi occurring in Wimmera soil

Method.

Numerous preliminary experiments using *Helminthosporium sativum* and *Fusarium culmorum* were made to evolve a satisfactory synthetic nutrient solution which would encourage the normal growth of these fungi. Various solutions were tried including that used by Steinberg (1936) for *Aspergillus niger*.

Some of the solutions, those containing ammonium nitrogen in particular, did not encourage normal sporulation and pigmentation. Starch and calcium chloride improved the growth of the fungi, notably in the case of *F. culmorum*. In this regard, Young and Bennett (1922) have reported that calcium stimulated the growth of a number of parasitic fungi grown in synthetic culture media, while Rogers (1938) obtained an appreciable increase in the growth of *Phymatotrichum omnivorum* by the addition of starch to the media.

The addition of amino nitrogen and vitamins to the solution also stimulated growth in some instances. (Table 1.)

As regards the heavy metals, several experiments were conducted to determine suitable concentrations. The following summarises the principal results obtained.—

A concentration of five parts per million of copper was found to depress the growth of *H. sativum* and *C. ramosa*, although *F. culmorum* appeared to tolerate this amount. On the other hand, all fungi appeared to tolerate concentrations of five parts per million of either zinc or iron. Two parts per million of molybdenum, cobalt, boron, or nickel depressed the growth of all the above fungi.

The composition of the final solution adopted was as follows:—

Di potassium hydrogen phosphate	1 0 grams per litre
Magnesium sulphate	0 5 " " "
Potassium chloride	0 5 " " "
Sodium nitrate	2 0 " " "
Sucrose	30 0 " " "
Starch	10 0 " " "
Calcium chloride	0 5 " " "
Asparagine	0 5 " " "
Glycine	0 2 " " "
Thiamin (Vitamin B_1)	5 parts per million
l-ascorbic acid (Vitamin C)	5 " " "
Nicotinic acid	5 " " "
Iron (as $FeSO_4 \cdot 7H_2O$)	1 " " "
Zinc (as $ZnSO_4 \cdot 7H_2O$)	1 " " "
Manganese (as $MnSO_4 \cdot 7H_2O$)	0 5 " " "
Copper (as $CuSO_4 \cdot 5H_2O$)	0 1 " " "
Double distilled water	1,000 ml.

Amino nitrogen was omitted for studies with *Helminthosporium sativum* and vitamins for studies with *Fusarium culmorum* (see Table 1). Pure synthetic vitamins were used. These were added to the solution after the purification process described below to prevent dissociation by heat.

The double distilled water was produced by a Pyrex glass still, and all chemicals were of analytical quality. Before the addition of the heavy metals and vitamins, the solutions were purified by

autoclaving with 15 grams of calcium carbonate per litre at one atmosphere pressure for twenty minutes and then filtering (Steinberg 1935). After this treatment the heavy metal contamination of the solution was tested by the dithizone method described by Stout and Arnon (1939).

The results of each of these tests showed that the total contents in each of the solutions of all the metals which react with dithizone was less than 0·02 parts per million.

The solutions were then distributed to pyrex glass erlenmeyer flasks of 200 c.cs. capacity and the heavy metals in solution were added by means of a pipette. All glassware was cleaned with 1 : 1 hydrochloric acid and rinsed in double distilled water before use. After sterilization, 5 c.cs. of a suspension of spores of the appropriate fungus was added to each flask, bringing the final volume of the solution per flask to 50 c.cs The cultures were then incubated at 25°C for fourteen days.

After incubation the cultures were filtered, and the mycelial mat was washed with hot water, dried in an oven at 103°C. for three hours and then weighed. Each treatment was replicated three times.

Results.

The comparative effects of amino nitrogen and vitamins on the growth of *F. culmorum*, *H sativum* and *C. ramosa* are shown in Table 1.

TABLE 1.—EFFECTS OF AMINO NITROGEN AND VITAMINS ON GROWTH OF CEREAL ROOT-ROT FUNGI IN NUTRIENT SOLUTIONS INCUBATED AT 25° C. FOR TEN DAYS.

—	*Fusarium culmorum.*		*Helminthosporium sativum.*		*Curvularia ramosa.*	
	Dry Weight of Fungus in Grams	Per cent of Base Medium	Dry Weight of Fungus in Grams	Per cent of Base Medium	Dry Weight of Fungus in Grams.	Per cent of Base Medium.
Base medium	0·366	100	0·388	100	0·531	100
Base medium + amino nitrogen*	0·554	151	0·352	91	0·664	125
Base medium + vitamins 5 p.p.m.†	0·324	89	0·489	126	0·529	100
Base medium + amino nitrogen + vitamins 1 p.p.m.	0·492	134	0·369	95	0·635	120
Base medium + amino nitrogen + vitamins 5 p.p.m.	0·449	123	0·382	99	0·606	114
Base medium + amino nitrogen + vitamins 20 p.p.m	0·520	142	0·362	93	0·655	123
Difference for significance	0·070	19·1	0·043	11·1	0·055	10·4

* Asparagine 0·5 grams and glycine 0·2 grams per litre.

† Thiamin (B_1) l-ascorbic acid (C), and nicotinic acid.

Although the general results of these experiments were in accord with those shown in Table 1, some variation in degree occurred, due probably to the use of different strains of the fungi. It is known that the physiology of such strains may vary. For instance, Pervukhina (1938) found that several different strains of species of *Fusarium* on wheat differed widely in the amount of amino nitrogen accumulated by them Such differences were correlated with differences in their pathogenicity to wheat.

While amino nitrogen stimulated the growth of *F. culmorum* and *C. ramosa*, it induced marked sectoring and usually a depression of the yield of *H. sativum*. While variants frequently occur in *Helminthosporium* Spp. (Christensen and Davies (1937)), their production in this instance by amino nitrogen, or in the case of other fungi by nitrite (Steinberg and Thom 1940) seems to offer a clue to their origin. The latter workers considered that the nitrite may have destroyed free amino acid groups in the hereditary mechanism.

The addition of vitamins markedly increased the yield of *H. sativum*, and in some instances, slightly increased that of *C ramosa*. On the other hand, the growth of *F. culmorum* was depressed. There is probably some relation between this result and the fact that on ordinary potato dextrose agar, *H. sativum* usually makes much slower growth than either *F. culmorum* or *C ramosa*. It is known that some fungi, at least, are capable of producing vitamins B_1 and C (Lewis 1938, Scheunert et al 1939, Robbins 1939), so that it seems probable, that the degree to which a fungus responds to the addition of vitamins to the media will be dependent on its inherent capacity to produce them itself.

White (1941) has demonstrated that the vegetative development of *Ophiobolus graminis* is dependent on the supply of biotin (Vitamin H) then thiamin (Vitamin B_1) and then a nutritional factor present in wheat straw, wheat roots, peptone and asparagine.

As regards the effects of heavy metal deficiencies, twelve separate experiments were sown as it was found that, even though the dithizone test indicated a low concentration of heavy metals in the purified solutions, there was in many cases sufficient of either of one of the heavy metals to support moderate growth. The particular contaminants were not consistent in each solution.

The results from typical experiments are given in Table 2, and the lowest percentage yield obtained from each deficiency treatments in all experiments with each fungus are set out in Table 3.

TABLE 2—RESULTS OF TYPICAL EXPERIMENT SHOWING THE EFFECTS OF DEFICIENCIES OF HEAVY METALS ON THE DEVELOPMENT OF ROOT ROT FUNGI GROWN IN NUTRIENT SOLUTIONS AT 25° C FOR 14 DAYS

Treatment	*Fusarium culmorum.*		*Helminthosporium sativum*		*Curvularia ramosa*	
	Dry Weight of Fungus in Grams	Percentage of Complete Solution	Dry Weight of Fungus in Grams	Percentage of Complete Solution	Dry Weight of Fungus in Grams	Percentage of Complete Solution
Complete solution	0.617	100	0.500	100	0.670	100
Manganese deficiency	0.450	73	0.410	82	0.435	65
Copper deficiency	0.400	65	0.400	81	600	90
Zinc deficiency	0.327	53	0.368	74	0.408	60
Iron deficiency	0.377	61	0.470	94	0.335	50
Difference for significance	0.094	5.5	0.062	12.4	0.053	7.9

These results indicate that the elements manganese copper zinc and iron are each essential to the normal development of some of the common root rot fungi occurring in Wimmera black soil In the case of *Phymatotrichum omnivorum* Blank (1941) has demonstrated the existence of important interactions between the elements particularly for the combinations iron and zinc and manganese and zinc

TABLE 3—LOWEST PERCENTAGE YIELDS OBTAINED FOR EACH HEAVY METAL DEFICIENCY TREATMENT IN ALL EXPERIMENTS

Treatment	*Fusarium culmorum* Per cent	*Helminthosporium sativum* Per cent	*Curvularia ramosa* Per cent
Complete solution	100	100	100
Manganese deficiency	73	7	[illegible]
Copper deficiency	64	8	87
Zinc deficiency	[illegible]	48	60
Iron deficiency	24	19	50

Certain features characteristic of deficiencies of these elements were observed These may be summarised as follows —

Zinc and Iron Deficiencies —These treatments led to a very reduced aerial growth although subsurface growth often occurred Waksman and Foster (1938) have similarly reported that only a sparse aerial mycelium was formed in their cultures of *Rhizopus nigricans* which were devoid of iron or zinc the addition of which profusely stimulated both vegetative development and sporulation

Manganese Deficiency —The effects of this treatment were very characteristic particularly on *H sativum* and *C ramosa* In the early stages growth was very reduced and typical small round colonies occurred either on the surface of the solution or on the bottom of the flask

Copper Deficiency:—Even though surface growth was often not reduced appreciably, pigmentation during the first few days was practically absent in *F. culmorum*, while in *H. sativum* and *C. ramosa* a pale yellowish-brown to light-greyish colouration was induced. This change in colour is similar to that induced in the spores of *Aspergillus niger* by copper deficiency (Steinberg 1935, Mulder 1938*b*). After approximately ten days, however, the pigmentation of the cultures gradually deepened until it was practically normal.

Discussion

The experiments have shown that the elements, manganese, copper, iron and zinc, which are known to be essential for the growth of higher plants, are also essential for the normal growth of *F. culmorum*, *H. sativum* and *C. ramosa*. The results of other workers cited earlier have similarly demonstrated that the need for heavy metals for normal growth is a phenomenon manifested by a wide variety of fungi.

Starkey (1938) has found that there can be no doubt that fungi develop vegetatively in the soil in the absence of appreciable amounts of readily decomposed organic matter. Fungus hyphae were found to be abundant even in fallow soil. Garrett (1939) in his review of the literature concluded that certain fungi pathogenic to plants, notably the wilt producing *Fusaria*, are also capable of living as saprophytes on the organic matter in the soil. Further Sadasivan (1939) has shown that *F. culmorum* plays an important part in the early decomposition of normal wheat straw buried in the soil. From their widespread distribution and persistence in the soil and their ready growth on artificial media, it is evident that other root-rot fungi such as *H. sativum* and *C. ramosa* are also capable of living as saprophytes in the soil. In this regard, Sandford (1933) has stated that soil borne pathogens such as *Ophiobolus graminis* and *H. sativum* can utilize soil nutrients for their own vital processes, but what nutrients were essential was not known.

These results therefore indicate that the accumulation in the soil of a large population of root-rot and other saprophytic fungi may effect the growth of the plant indirectly, by competing with the roots of the plant for the soil minerals which are essential to the normal development of both the soil fungi and the plant.

Further investigations relevant to this conclusion are described later in this paper.

Influence of the Soil Flora on the Availability of Soil Minerals.

It has been shown (Starkey 1931, Clark 1940, Lochhead 1940, Timonin 1940*a*) that the presence of plant roots may exercise a profound effect on the soil microflora. Compared with the

population in soil distant from the roots, very large accumulations of bacteria and actinomycetes, and to a lesser extent of fungi occur in the rhizosphere.

West and Lochhead (1940) found that these accumulations were associated with the excretion by the roots of stimulative substances such as thiamin, biotin, and amino-nitrogen. Further work by Lochhead et al (1940) and Timonin (1940*b*) has indicated that the rhizosphere of plants susceptible to soil-borne pathogens harboured larger numbers of fungi and bacteria than those of resistant plants. These results suggested the existence of inherent differences between resistant and susceptible varieties, resulting in a more pronounced " rhizosphere effect " in the case of susceptible plants.

Such large populations of micro-organisms would require a greatly increased share of the mineral nutrients in the soil. It is probable that plant roots are unable to compete with the micro-organisms for the soil minerals on an equal basis. In soils, therefore, where a limited available supply of any mineral existed, a deficiency of that mineral in the plant may develop, as a result of the competition of the soil flora, with a consequent injurious effect on growth. It may well be that some of the symptoms associated with soil-borne diseases may be due, in some instances at least, as much to physiological disturbances in the plant arising from this and other causes as to the actual parasitism of the organisms concerned.

The possibility of saprophytic soil fungi and bacteria rendering the soil minerals unavailable to the higher plants has been recognized only comparatively recently. " Grey Speck " disease of oats induced by manganese deficiency (Leeper and Swaby 1940), " Reclamation disease " of oats induced by copper deficiency (Mulder 1938*a*), and " Little Leaf " or " Rosette " disease of fruit trees in America induced by zinc deficiency (Ark 1937, Chandler 1937, Hoagland et al 1937) have been shown to be related to the activities of manganese, copper or zinc fixing soil micro-organisms respectively. It was found that soils in which " little leaf " and related diseases occur can supply an adequate amount of zinc to the plant after they have been sterilized, thus curing the " little leaf " condition Piper (1938) has also demonstrated that " reclamation disease " of oats in certain areas in South Australia is associated with the lack of available copper in the soil rather than with the total amount present. The availability of the copper to the plant was increased by partial sterilization of the soil, and the plants grown in the autoclaved soil developed normally without any signs of the disease (Waite Institute 1939). In regard to the Robe district in South Australia, it is of interest to note that Riceman and Anderson (1941) have reported that, in the presence of applied copper, the addition of zinc sulphate increased the grain yield of oats. Manganese deficiency may be cured by sterilization with

formalin (Gerretson 1935) or by waterlogging the soil (Leeper 1940). In the latter case lack of aeration would considerably curtail the activities of manganese-fixing organisms. Waksman (1931) has discussed the effect of heat in increasing the solubility of soil minerals

It is recognized that the availability of soil minerals may be affected by factors other than the biological status of the soil. Hibbard (1936, 1940 (*b*)) states that physical, chemical and biological conditions in soil, the nature of the plant and need for specific nutrients, &c., all effect the availability of soil nutrients. Fixation of minerals in the soil may be brought about by anion exchange, molecular adsorption and chemical precipitation. Cation adsorption by bacteria has been demonstrated by McCalla (1940)

It is well established that changes in the soil reaction can appreciably effect the availability of soil minerals (Aleshin and Igritskaia (1938), Chapman et al (1939), Eaton and Wilcox (1939), Hibbard (1940*a*), Leeper (1935), McGeorge (1939), Midgley and Dunklee (1940) and others). It must be remembered, however, that while a change in the soil reaction may effect the availability of minerals, it may concomitantly have and appreciable effect on the biological status of the soil. It is considered that the correlation between these two changes has not been satisfactorily investigated. Leeper (1940) has reported that manganese deficiency disease of oats may be cured either by acidification of the soil below pH 6·5 or by alkalinization with caustic soda raising the pH over 8·5 Waksman (1931) has shown that the optimum reaction for most soil organisms is either around neutral or slightly alkaline, and that bacteria, and to a lesser degree, fungi are limited by increasing acidity. Similarly bacteria, fungi and protozoa are susceptible to increasing alkalinity and most forms are inhibited above pH 9·5. However, few crop plants will grow below pH 3·5 or above pH 9·0.

It may well be that the deleterious effects which sometimes accompany the liming of acid soils may be due in a large degree to the establishment of a more favourable biological environment leading to an increase in the population of soil micro-organisms and a consequent increased demand for the available soil nutrients.

Further reference to the effects of the soil micro-organisms on the availability of the soil minerals is made in the final discussion of the data presented in this paper.

Effects of Soil Sterilization on Mineral Composition of Wheat Plants.

Analyses of wheat plants grown in the Wimmera on black ground (Millikan 1940) have shown that even plants receiving no zinc sulphate have a relatively high zinc content. This indicates that the responsiveness of plants grown in Wimmera black soil to applications of zinc sulphate is not related to a complete

lack of zinc in the rhizosphere, but rather to a slightly insufficient supply in an available form. This insufficiency was made good by treating the plants with zinc sulphate, and the small increase in the zinc concentration which resulted from this treatment was accompanied by a marked improvement in the general growth of the plants.

If, as suggested above, the deficiency of zinc available to the plant in the soil be due to competition between the plant and the soil flora for the soil zinc, it should also be possible to make up this insufficiency by sterilizing the soil to eliminate this competition, providing an adequate total amount of zinc existed in the soil

Experiments have been conducted at the Plant Research Laboratory, Burnley, during the three seasons 1938-40 inclusive, to determine, in the first instance, whether the availability to the plant of the zinc and other minerals in Wimmera black and red soils was affected by soil sterilization

Method.

In 1938 and 1939 the comparative effects of the application of zinc sulphate in conjunction with superphosphate to sterilized and unsterilized Wimmera black fallow soil from Nhill and Salisbury were studied

In the first (1938) season metal containers six inches in diameter and six inches deep were used to hold the soil. The inside of each container was coated with a thin layer of high grade paraffin wax before use and the superphosphate and zinc sulphate were mixed with the top two inches of soil only. The treatments studied in both unsterilized and sterilized soil were:— Superphosphate 1½ cwt per acre, and Superphosphate 1½ cwt + Zinc sulphate 30 lb. per acre, respectively. The soils were sterilized by autoclaving at two atmospheres pressure for two hours. The soils were air dry at the time of sterilization. Seven plants of Free Gallipoli wheat were grown to maturity in each pot, while the moisture content of the soil was kept constant during the experiment at 50 per cent. of its waterholding capacity by the addition of distilled water every second day. Each treatment was replicated four times.

During 1939 Nhill black fallow soil only was used in paraffined wooden boxes two feet square by six inches deep The treatments studied were the same as in the previous year. The zinc sulphate and/or superphosphate were mixed with the top two inches of soil in each box. Free Gallipoli wheat was again used, the grains being spaced one inch apart each way. One composite sample of plants was taken at four, six and nine weeks after germination from the three replicates of each treatment, and were submitted to the Agricultural Research Chemist for ash analyses.

A study of the comparative effects of soil sterilization, of Nhill black and red fallow soils respectively, on the mineral composition of wheat plants subsequently grown therein was made in 1940,

Paraffined wooden boxes were again used, but were two inches deeper than those used in the previous season. No superphosphate or zinc sulphate was applied to the soils, and the sterilization treatment of air dry soil was at ½ atmosphere for ¾ hour, immediately prior to sowing. Each treatment was replicated three times. Composite samples of plants from the three replicates of each treatment were obtained at four and eight weeks after germination and were submitted to the Agricultural Research Chemist for ash analyses.

In the field at Nhill, wheat plots were sown without fertilizers on the same red and black fallow areas respectively from which the soils for the 1940 experiments at Burnley were obtained. Ash analyses were made by the Agricultural Research Chemist on plant samples obtained from these plots at six weeks after germination to determine whether the mineral compositions of the plants grown under field conditions differed to any marked degree from those of the plants grown in the same soils at Burnley.

Results.

1938.—The growth obtained in the sterilized soil was very much superior to that which occurred in unsterilized soil, both as regards height and depth of colour. The plants in the unsterilized soil developed a marked yellowing of the tips of the leaves such as occurs commonly in the field at Nhill

In unsterilized soil, an improvement in growth due to the application of zinc sulphate was first noticeable when the plants were in the third leaf stage. Later the zinc treated plants became somewhat taller and showed better tillering.

In the sterilized soil the zinc treatment had no apparent effect on growth up to the heading stage. At this stage, however, it was observed that soil sterilization exercised a profound influence on the response of the wheat to zinc applications. Whereas in the unsterilized soil the effect of the zinc sulphate application was similar to that resulting under field conditions (i.e., to induce the earlier appearance of the ears), the zinc treatment in the sterilized soil consistently retarded the date of appearance of the ears by one week. (Plate X, fig. 5.)

1939.—The effect of soil sterilization on growth was first noticeable three weeks after germinations. At this stage the plants growing in unsterilized soil showed poorer growth, were paler green in colour, and in many instances the tips of the leaves were beginning to brown. Later the development of the plants growing in unsterilized soil became very inferior to that of the plants in sterilized soil.

As regards the effects of the zinc sulphate applications, little difference in growth at nine weeks after germination was induced in the plants growing in unsterilized soil. It was observed,

however, in the case of the sterilized soil series, that the average weight per plant in samples obtained at six and nine weeks after germination was reduced by the addition of zinc sulphate. This confirms the observation made in the previous season that the application of zinc sulphate to sterilized Wimmera black soil had a harmful effect on the growth of wheat.

The analyses of the plants shown in Table 4 indicate that the sterilization of the soil had a profound effect on the mineral composition of the plants. Their silica (SiO_2), and lime (CaO) concentrations were reduced, while increases in their phosphoric acid (P_2O_5), potash (K_2O), zinc (Zn), manganese (Mn), and nitrogen (N) concentrations occurred. Not only was the percentage of these latter constituents increased but the total amount of them absorbed would be very much greater than in the unsterilized soil owing to the great improvement in growth promoted by soil sterilization.

TABLE 4.—SHOWING THE EFFECT OF STEAM STERILIZATION OF NHILL BLACK FALLOW SOIL ON THE MINERAL COMPOSITION, AT FOUR, SIX AND NINE WEEKS AFTER GERMINATION, OF FREE GALLIPOLI WHEAT GROWN THEREIN AT BURNLEY DURING 1939 RESULTS OF ANALYSES AS PER CENT ON DRY BASIS

—	Unsterilized		Sterilised	
	Superphosphate 1¼ cwt per Acre	Superphosphate 1¼ cwt + Zinc Sulphate 30 lb per Acre	Superphosphate 1¼ cwt per Acre	Superphosphate 1¼ cwt + Zinc Sulphate 30 lb. per Acre
(a) Analyses Four Weeks after Germination.				
Crude Ash	14·45	14·63	17·41	17·86
Silica Free Ash	9·88	9·99	13·08	12·94
Silica (SiO_2)	4·57	4·64	4·33	4·93
Phosphoric Acid (P_2O_5)	1·57	1·74	2·58	2·60
Lime (CaO)	1·07	1·11	0·96	0·95
Potash (K_2O)	3·77	3·70	5·24	5·51
Zinc (Zn) parts per million	34	39	54	78
(b) Analyses Six Weeks after Germination.				
Crude Ash	13·67	14·48	17·37	16·79
Silica Free Ash	8·49	8·27	14·07	13·59
Silica (SiO_2)	5·18	6·21	3·30	3·20
Lime (CaO)	1·16	1·17	0·94	0·92
Phosphoric Acid (P_2O_5)	1·17	1·22	3·60	3·42
Potash (K_2O)	3·10	2·61	5·93	5·95
Zinc (Zn) parts per million	31	35	57	74
(c) Analyses Nine Weeks after Germination.				
Nitrogen	1·20	1·21	2·42	2·50
Crude Ash	19·41	16·90	14·86	14·02
Silica Free Ash	7·00	6·49	9·20	9·67
Silica (SiO_2)	12·41	10·41	5·66	4·35
Lime (CaO)	1·10	1·15	0·81	0·79
Phosphoric Acid (P_2O_5)	0·68	0·75	2·22	2·26
Potash (K_2O)	2·32	2·25	4·22	4·45
Zinc (Zn) parts per million	32	33	56	66
Manganese (Mn) parts per million	114	107	143	168

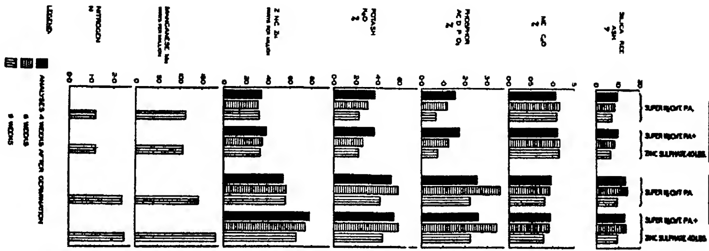

Fig. 1.—Results of analyses given in Table 4 showing the effect of steam sterilization of Nhill black fallow soil on the mineral composition at four, six and nine weeks after germination, of Free Gallipoli Wheat grown therein at Burnley during 1939. Analyses on dry basis.

The fact that the concentration of zinc present in the plants grown in sterilized soil treated with superphosphate only, was considerably higher than in the unsterilized soil series plants treated with superphosphate plus zinc sulphate, indicates that when sterilized, the Wimmera black soil is capable of supplying an adequate amount of zinc in a form readily available to the plant.

From these figures it also appears probable that the application of zinc sulphate to sterilized soil may even increase the amount of this element available to the plant above the optimum point and thus induce some deleterious effect on the growth of the plant, such as retardation in the date of heading noted in 1939 or decreased weight per plant referred to above. The analyses show that such plants contained the highest concentration of zinc. Although plants require minute quantities of elements such as zinc, manganese and copper for normal growth Arnon and Stout (1939) have stated that most plants are also injured by very small increases in the concentrations of such elements in the plant.

The zinc concentration reaches a maximum early in the development of the plant and subsequently falls to a very low figure after heading. It is probable that the total amount of zinc in the plant does not decrease after the maximum concentration has been passed but that the percentage decreases due to "dilution" with dry matter.

1940.—Similar improvements in growth to those described above for the previous two seasons resulted from the steam sterilization of both red and black fallow soils from Nhill. The unsterilized soil plants, besides being not as tall as the plants grown in sterilized soil, were pale green in colour and showed marked yellowing of the tips of the leaves; these latter symptoms were cured by soil sterilization. Yellowing of the tips of the leaves also occurred in the case of the plants under field conditions at Nhill.

A comparison of the analyses of these field grown plants at six weeks after germination, with those of plants grown in the same soils in boxes at Burnley at four and eight weeks after germination, show very close agreement after allowance is made for the variations in the percentages of the constituents which occur with age (Table 5).

In the black soil, the changes in the mineral constituents of the plants induced by sterilization were similar to those recorded in 1939, i.e., the percentages of phosphoric acid (P_2O_5), potash (K_2O), zinc and manganese were increased In the 1940 series the percentages of lime (CaO) and copper were also increased in the plants grown on sterilized soil. Sterilization had no effect on the percentage of magnesia (MgO) in either season.

In the plants grown on red soil, sterilization induced similar changes in the percentages of mineral constituents to those which occurred on black soil, i.e., the percentages of lime (CaO), phosphoric acid (P_2O_5), potash (K_2O), magnesia (MgO), zinc, manganese and copper were increased. The relative increase in the percentage of manganese was much greater in red than in black soil, while only a slight increase in the precentage of zinc was recorded for the former soil at eight weeks after germination.

An interesting effect of soil sterilization common to both soils was a decrease in the percentage of iron (Fe) in the plants. The reason for this change is at present unknown. It may be associated with some antagonistic effect in the plant resulting from the other profound changes induced in mineral composition by soil sterilization.

In view of the much superior growth of the sterilized soil plants compared with those grown in unsterilized soil, however, it is possible that the total amount of iron absorbed was not decreased by sterilization.

One further point to be noted from Table 5, is that differences in the normal percentages of mineral constituents occurred between the plants growing on Wimmera black and red soils respectively. The red soil plants contained the highest percentages of phosphoric acid (P_2O_5), zinc and copper (the latter at eight weeks after germination) and the lowest percentages of lime (CaO), potash (K_2O), manganese and iron. The percentages of magnesia (MgO) and nitrogen (N) recorded for the two types of soil were similar.

These differences in the normal composition of the plants grown on the two types of soil are probably closely connected with, firstly, the lack of response in wheat to applications of zinc sulphate in the field; secondly, the relatively smaller response on red than on black fallow soil from the application of such mineral mixtures as have been applied to date. The latter effect is described in detail later in this paper (Tables 8, 10, and 11.)

These experiments have shown that certain plant nutrients become more readily available to the plant as a result of the sterilization of Wimmera red and black soils leading to improved growth and colour in the plants. This result is similar to that reported by Piper (1938), and cited above, in relation to copper deficiency disease of oats in South Australia.

It was recognized that the availability of soil minerals can be appreciably affected by changes in the soil pH. The reactions of steam sterilized and unsterilized black and red fallow soils from Nhill have been determined, to discover whether the marked increases in mineral availability recorded above as a result of steam sterilization of these soils could be attributed, in part at least, to possible changes in pH induced by the heat treatment.

From the results below it will be seen that steam sterilization had no effect on the reaction of the soil:—

Black fallow soil—unsterilized	pH 8·5
Black fallow soil—steam sterilized	pH. 8·5
Red fallow soil—unsterilized	pH. 6·2
Red fallow soil—steam sterilized	pH. 6·3

TABLE 5.—ANALYSES, ON DRY BASIS, OF FREE GALLIPOLI WHEAT PLANTS GROWN ON WIMMERA RED AND BLACK FALLOW SOILS RESPECTIVELY AT NHILL AND BURNLEY DURING 1940, SHOWING NORMAL DIFFERENCES IN MINERAL COMPOSITION OF THE PLANTS, AND THE COMPARATIVE EFFECTS OF STERILIZATION OF EACH SOIL ON THE AVAILABILITY OF MINERALS TO THE PLANT.

—	Red Fallow Soil.			Black Fallow Soil.		
	Field Grown Plants (Nhill).	Unsterilized Soil (Burnley).	Sterilized Soil (Burnley).	Field Grown Plants (Nhill).	Unsterilized Soil (Burnley).	Sterilized Soil (Burnley).
(a) Analyses Four Weeks after Germination.						
Lime (CaO) per cent.	..	0·43	0·65		0·61	0·78
Magnesia (MgO) per cent. ..	..	0·49	0·70	..	0 48	0·49
Potash (K_2O) per cent. . .	..	4·57	5·50	..	5·23	5·73
Phosphoric acid (P_2O_5) per cent. .	..	1·60	2 51	..	1 06	1·93
Zinc (Zn) parts per million ..	..	54	52	..	30	45
Copper (Cu) parts per million .	.	17	21	..	16	15
Manganese (Mn) parts per million .	.	38	154	..	90	138
Iron (Fe) parts per million ..	..	21	24	..	84	59
(b) Analyses Six Weeks after Germination.						
Magnesia (MgO) per cent. ..	0 50	..	..	0 49	..	..
Phosphoric Acid (P_2O_5) per cent. ..	0 76	..	.	0 71	..	..
Nitrogen (N) per cent. .. .	5 77	..	..	5·55	..	..
Zinc (Zn) parts per million .	28	.	.	21	..	..
Copper (Cu) parts per million ..	18		..	18	.	..
Manganese (Mn) parts per million ..	48	.	..	70	..	..
Iron (Fe) parts per million .	68	..	..	85	.	
(c) Analyses Eight Weeks after Germination.						
Lime (CaO) per cent.	..	0·43	0·56	..	0·82	0 96
Magnesia (MgO) per cent. ..	..	0·39	0 37	.	0 35	0 35
Potash (K_2O) per cent.	..	3·58	5 06	..	4·43	5·94
Phosphoric Acid (P_2O_5) per cent. ..	..	0 86	1·65	.	0·63	1 85
Zinc (Zn) parts per million ..	..	30	36	..	27	47
Copper (Cu) parts per million .	.	24	25	..	5	8
Manganese (Mn) parts per million ..	..	50	251	.	49	167
Iron (Fe) parts per million .	..	45	25	..	35	27

Further, as shown in Table 8, soil sterilization with 2 per cent. formalin produced a similar improvement in growth to that resulting from steam sterilization.

EFFECTS OF RE-INOCULATION OF STERILIZED SOIL WITH SOIL INHABITING ORGANISMS.

Preliminary investigations designed to be complementary to the soil sterilization studies reported above have been conducted at Burnley during 1939 and 1940. The object of this work was to

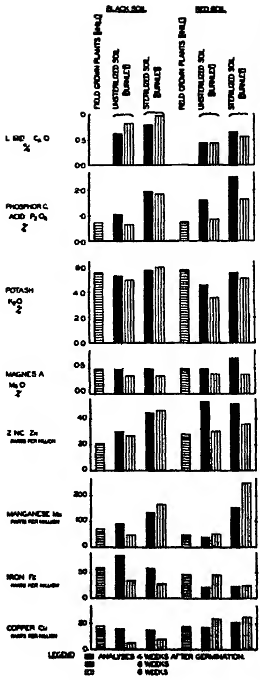

FIG. 2.—Results of analyses, given in Table 5 of Free Gallipoli wheat plants grown on Wimmera red and black fallow soils respectively at Nhill and Burnley during 1940, showing normal differences in the mineral composition of the plants and the comparative effects of sterilization of each soil on the availability of minerals to the plant Analyses on dry basis

determine whether the activities of soil-inhabiting bacteria and fungi in the rhizosphere in Wimmera soil affect the growth of the plant indirectly by using the soil nutrients for their own vital processes, thus reducing the amount available to the plant.

The results of nutritional studies on the heavy metal requirements of soil-inhabiting root-rot fungi have been described above. In addition to this work experiments were made on the mineral relationship of wheat plants grown in sterilized Wimmera black fallow soil re-inoculated with some of the normally occurring soil fungi and bacteria.

Method.

In 1939 portions of air dry black fallow soil were steam sterilized at two atmospheres pressure for two hours, and then inoculated with a mixed suspension of soil bacteria in water two months prior to sowing with Free Gallipoli wheat. After inoculation the moisture content of the soil was kept constant at 50 per cent. of its water holding capacity. In the meantime a further portion of the original soil was kept air dry and was sterilized immediately prior to sowing. Paraffined containers 6 inches in diameter and 6 inches deep were used to hold the soil. At sowing time the top two inches of soil in each container was treated with either superphosphate $1\frac{1}{2}$ cwt. per acre or superphosphate $1\frac{1}{2}$ cwt. + Zinc sulphate 30 lb. per acre respectively. Each treatment was replicated four times and seven grains were sown in each pot. The moisture content of the soil was kept constant by the addition of distilled water every second day.

In 1940 paraffined wooden boxes 2 feet square by 8 inches deep were used to hold the soil which was sterilized two months before sowing by autoclaving at half an atmosphere pressure for $\frac{3}{4}$ hour. Separate portions of this sterilized soil were immediately re-inoculated with a suspension in water of one of the following mixtures of organisms:—Root-rot fungi (*Curvularia ramosa, Helminthosporium sativum, Fusarium culmorum*), Saprophytic fungi (*Rhizopus sp.* and *Pennicillium spp.*), or a mixture of soil bacteria. To a further portion of sterilized soil 1 per cent. of unsterilized soil was added.

The control treatments of sterilized soil only and unsterilized soil were set up at this time and were maintained under comparable conditions to the inoculated series.

In the meantime a further portion of unsterilized soil was kept air dry and was sterilized immediately prior to sowing. Each treatment was replicated three times. No fertilizer was applied in this experiment, and approximately 500 grains of wheat were sown in each box.

Composite samples of plants were obtained from the three replicates of each treatment at both four and eight weeks after germination and were submitted to the Agricultural Research Chemist for ash analyses.

Results.

1939.—In the uninoculated sterilized soil, it was found that the application of zinc sulphate retarded growth, in contrast to the stimulation of growth promoted by this treatment in the unsterilized soil. These effects were in accord with the results of other experiments with fallow soil reported above. The retardation of growth in sterilized soil was first noticeable in the fourth leaf stage, six weeks after germination.

On the other hand, the zinc sulphate application to sterilized soil re-inoculated with bacteria definitely stimulated growth. This stimulation was first noticeable approximately eight weeks after germination.

From this preliminary experiment it was evident that the zinc responsiveness of Wimmera black fallow soil which is destroyed by steam sterilization can be re-established by inoculating such sterilized soil with soil bacteria.

1940.—The big improvement in growth due to soil sterilization which occurred in this experiment was similar to that described above for other experiments, where a similar treatment was given. The growth in the soil sterilized two months prior to sowing was slightly superior to that in the soil sterilized immediately prior to sowing.

At the time of first sampling four weeks after germination, no obvious differences in growth between the sterilized only soils and the sterilized soils re-inoculated with soil organisms was discernable.

At eight weeks after germination, however, when the second samples were taken, the plants in the inoculated sterilized soils appeared slightly paler green in colour than the sterilized soil controls. The tips of the leaves of the plants in the sterilized soil inoculated with root-rot fungi were slightly yellowed.

The results of the analyses made on these samples are shown in Table 6. Several points of some significance may be noted from a study of these figures. In the first instance a gap of two months between sterilization and sowing evidently had a beneficial effect on the availability of potash (K_2O), magnesia (MgO), and manganese, to the plant. On the other hand, the lime (CaO) and phosphoric acid concentrations were higher in the plants grown in soil sterilized immediately prior to sowing. It is known that after soil sterilization, time is sometimes required before the full benefit of the treatment on subsequent plant growth is achieved.

A time factor doubtless operates in relation to the autolysis of soil organisms subsequent to soil sterilization, and the concomitant release of plant nutrients.

TABLE 6.—PRELIMINARY EXPERIMENT WITH WIMMERA BLACK FALLOW SOIL CONDUCTED AT BURNLEY DURING 1940, SHOWING COMPARATIVE EFFECTS OF STERILIZATION TWO MONTHS PRIOR TO SOWING, IMMEDIATE RE-INOCULATION OF SUCH STERILIZED SOIL WITH SOIL FUNGI OR BACTERIA, AND STERILIZATION JUST PRIOR TO SOWING RESPECTIVELY, ON THE MINERAL COMPOSITION OF FREE GALLIPOLI WHEAT PLANTS GROWN THEREIN. ANALYSES ON DRY BASIS.

—	Unsterilized.	Sterilized (April).	Sterilized (June)	Sterilized (April) + Root Rot Fungi.	Sterilized (April) + Saprophytic Fungi.	Sterilized (April) + Soil Bacteria.	Sterilized (April) + 1 per cent. Unsterilized.
(a) Analyses Four Weeks after Germination.							
Lime (CaO) per cent.	0·61	0·75	0·78	0·89	0·85	0·76	0·89
Magnesia (MgO) per cent. ..	0·46	0·48	0·49	0·51	0·52	0·56	0·52
Potash (K_2O) per cent.	5·23	5·50	5·72	5·61	5·68	6·11	5·50
Phosphoric acid (P_2O_5) per cent. ..	1·06	1·75	1·93	1·55	1·77	1·52	1·45
Zinc (Zn) parts per million ..	30	41	45	47	46	49	46
Copper (Cu) parts per million ..	16	20	15	24	34	30	15
Iron (Fe) parts per million ..	54	55	59	71	50	48	45
Manganese (Mn) parts per million	90	138	133	123	120	117	130
(b) Analyses Eight Weeks after Germination.							
Lime (CaO) per cent. . ..	0·82	0·81	0·96	0·94	0·94	0·98	0·90
Magnesia (MgO) per cent. ..	0·35	0·47	0·35	0·34	0·35	0·38	0·46
Potash (K_2O) per cent. ..	4·43	6·93	5·94	6·17	6·40	6·69	6·57
Phosphoric Acid (P_2O_5) per cent...	0·63	1·48	1·85	1·61	1·53	1·46	1·11
Zinc (Zn) parts per million ..	27	49	47	41	50	44	36
Copper (Cu) parts per million ..	5	7	8	9	14	9	9
Iron (Fe) parts per million ..	35	31	29	29	29	26	31
Manganese (Mn) parts per million	49	208	167	140	149	161	151

A second point of importance to be noted from the results is that the general nutritional level of the plants in the sterilized re-inoculated soils even four months after inoculation is still very much higher than that of the unsterilized soil plants. It is evident, therefore, that to obtain the full effects of re-inoculation of sterilized soil, analyses should be made later than eight weeks after germination. Probably more reliable information would be obtained by making analyses on the " residual effect " in stubble sown plants in the season after inoculation. Fungi often grow only moderately well on sterilized soil without the addition of stimulating substances. Such substances are secreted by plant roots. References to this " rhizosphere effect " have been cited at the beginning of this section. It seems probable, therefore, that the increase in the organisms inoculated into sterilized soil would be greater after the plants had become established than before.

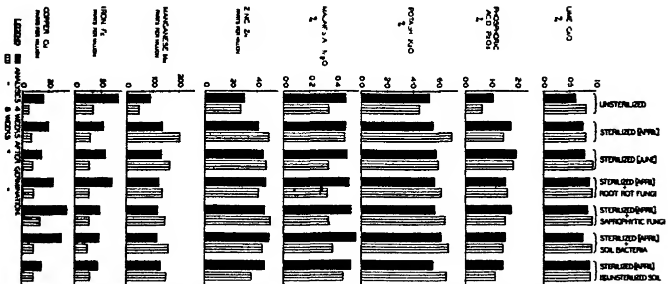

FIG 3 —Results of analyses given in Table 6 of a preliminary experiment with Wimmera black fallow soil conducted at Burnley during 1940 showing comparative effects of sterilization two months prior to sowing immediate re inoculation of such sterilized soil with soil fungi or bacteria and sterilization just prior to sowing respectively, on the mineral composition at four and eight weeks after germination of Free Gallipoli wheat plants grown therein Analyses on dry basis

This latter is in accord with the analyses of the plants. Whereas the inoculations of sterilized soil had little effect on the percentage composition of the plants at four weeks after germination, the analyses four weeks later show some marked changes. Compared with the control plants in Sterilized (April) Soil, the analyses eight weeks after germination showed lower percentages of phosphoric acid (P_2O_5), potash (K_2O), magnesia (MgO), zinc and manganese in some or all of the inoculation treatments.

The results of this preliminary experiment have shown that the presence of soil inhabiting organisms in the rhizosphere may decrease the availability of certain mineral nutrients to the plant.

The variable results reported from inoculation tests using sterilized soil may well be due to the fact that the effects of the competition between the plant and the organisms for the soil minerals was not apparent, owing to the marked increase in the amount of available soil minerals due to the sterilization treatment. The time factor is obviously very important in all such experiments. This may be the explanation of the results of Sandford (1941) who found that *Rhizoctonia solani* was not virulent in sterilized soil.

Mineral Treatment in Relation to the Apparent Severity of Root-rot Disease.

The literature on the effects of manuring and other treatments on the development of soil-borne diseases in plants has been reviewed by Garrett (1939).

Deficiencies of available plant nutrients in the soil may be induced by a variety of causes; some references have been cited earlier. Where such deficiencies exist, the resulting symptoms in the plant such as restricted growth and reduced yield, would, if associated with the occurrence of root-rot lesions in the plants, be liable to be wrongly attributed to the direct effects of root-rot organisms. The apparent severity of the root-rot disease would therefore appear to be greater than its actual severity. Alleviation of the soil deficiency by suitable treatment may therefore decrease the apparent severity of the disease without actually decreasing the number of lesions on the roots of the affected plants. This is probably the explanation of the results of Russell and Sallans (1940), who found that although the applications of phosphatic fertilizers frequently increased the yield of wheat, there was usually, if anything, a slight increase in the common root-rot disease rating of the fertilized plants. In view of the increased yields produced by the fertilized plants, however, it is obvious that the apparent severity of the disease must have been reduced.

Other instances have been recorded where the occurrence of soil mineral deficiencies had appreciable effects on the apparent severities of disease in susceptible plants grown in those soils

(Samuel 1934, Miles 1936, Millikan 1938, Walker and Musbach 1939, Vanterpool 1940). The application of the appropriate mineral not only cured the deficiency, but also reduced the apparent severity of the disease. This latter beneficial effect is evidently bound up more with the curing of a physiological disorder, resulting in an increase in the vigor and yield of the plant, than with any increase in the plant's resistance to fungal attack.

In a study of the root-rot problem, it is therefore of paramount importance to distinguish between symptoms caused by physiological disorders in the plant induced by external factors and those caused by the direct effects of the root-rot organisms.

The results recorded earlier in this paper have indicated that the fungi and bacteria inhabiting Wimmera black soil may exercise an indirect, harmful effect on plant growth by competing with the plant for the soil nutrients. It would follow, therefore, that a mineral treatment would help to overcome the indirect effects of these organisms on plant growth by supplying additional nutrients in a form immediately available to the plant, thus producing an improvement in growth at least approaching that resulting from steam sterilization.

Where other environmental factors such as soil moisture were optimum for growth, the presence of soil inhabiting organisms which may become plant pathogens would tend to prevent such a treatment from inducing an improvement in growth completely comparable with the effect of sterilization. Further, to obtain the maximum response in growth the ingredients of the treatment applied would necessarily need to be of a proper kind and proportion to meet the particular needs of the soil concerned. Such a treatment could only be developed after much research.

Under these conditions, the relative growths obtained in the sterilized soil, and in unsterilized soil supplied with additional nutrients, would give an indication as to the real effects on plant growth of the root-rot organisms present in that soil. Such an experiment, it seems to the writer, is the only means by which the actual pathogenicity of root-rot organisms can be evaluated.

To determine the effects of mineral treatment on the development of cereals grown on Wimmera soil, experiments have been conducted in the greenhouse at the Plant Research Laboratory, Burnley, in 1939 and 1940, and in the field on the farm of Mr. C. P. Dahlenburg, Nhill, during the seasons 1938 to 1940 inclusive. The effects of such treatments on the abundance of root-rot lesions on the plant was also determined in the field experiments.

GREENHOUSE EXPERIMENTS, 1939-40.

Nhill black wheat stubble soil was selected for the first experiment which was conducted during 1939. The growth of wheat and oats on such soil is usually very poor. The following year the experiments were extended to include Nhill black and red fallow soils in addition to the black stubble soil.

Method.

Each treatment was replicated four times and all fertilizers and minerals were applied to the top two inches of soil only in each container, which measured six inches in diameter by six inches deep. Each was coated with a thin layer of high grade paraffin before use. With the exception of the first experiment in 1939, the soils at the time of sterilization were air dry, and the treatment was for three-quarters of an hour at one-half atmosphere pressure.

Before sowing, the moisture content of the soil was adjusted to 50 per cent. of its moisture holding capacity, and was kept constant at this figure during the experiment by the addition of distilled water thrice weekly. Seven grains of Free Gallipoli wheat were sown in each pot.

At the termination of the 1940 experiment, the dry weights of the plants were obtained.

The treatments studied in each season were as follow:—

1939.—A dressing of either superphosphate 1½ cwt. per acre, or superphosphate 1½ cwt. + zinc sulphate 40 lb. per acre was applied to unsterilized soil, sterilized soil (half atmosphere for half hour) and sterilized soil (two atmospheres for two hours) respectively. A further treatment consisting of unsterilized soil + mineral mixture (see Table 7 for composition) was included.

1940.—The treatments applied to each type of soil in 1940 are shown in Tables 7 and 8.

TABLE 7.—GREENHOUSE WHEAT EXPERIMENTS, BURNLEY, 1939-40, SHOWING THE COMPOSITIONS, IN POUNDS PER ACRE, OF THE MINERAL MIXTURES APPLIED TO THE VARIOUS TYPES OF NHILL SOIL (I.E., BLACK FALLOW, BLACK WHEAT STUBBLE AND RED FALLOW) USED

Constituent.	1939	1940 Mixtures.							
		1	2.	3.	4	5	6	7	8.
Superphosphate	168	112	168	168	168	56	56	168	168
Sulphate of ammonia ..	112	28	112	112	112	112	112	112	112
Zinc sulphate	40	20	20	20	20	..	..	20	..
Manganese sulphate ..	40	15	15	30	30	30	30	15	..
Sulphate of potash ..	..	25	25	25	25	25	25	25	25
Magnesium sulphate ..	30	..	..	20	30	30	..	20	20
Copper sulphate	4	..	..	3	4	4	..	5	..
Iron sulphate	10	..	..	15	15	15	15	15	..
Cobalt chloride	2	..	..	2	2	2	..	4	4
Ammonium molybdate ..	2	..	..	2	2	2	..	4	4
Nickel sulphate	1	.	..	2	2	2	..	4	4
Borax	..	..	..	2	2	2	..	..	..

Results.

Marked differences in growth were induced by certain of the treatments (Plate X., fig. 6; Plate XI., fig. 7). As seen in Table 8 the greatest increases were promoted by soil sterilization with either steam or formalin. The mineral mixtures also induced appreciable increases in growth, particularly in the black stubble soil in both 1939 and 1940. In this soil the appearance of the mineral treated plants up to the heading stage was only very slightly inferior to that of the sterilized soil plants. Growth on stubble is normally much inferior to that on fallow.

One point of particular interest revealed in Table 8 is that whereas the addition of the elements magnesium, copper, cobalt, molybdenum, nickel and boron to the mixtures applied to black fallow soil significantly depressed the yield, their inclusion in the black stubble soil mixtures caused a very appreciable increase in the weight of dry matter produced. Evidently the process of fallowing Nhill black soil increases the availability of some, at least, of the elements listed above. In this regard it is of interest to note that in Western Australia the growth of "rosetted" pines suffering from zinc deficiency (Kessell and Stoate 1936) has been found to be stimulated by injections of manganese, iron, cobalt, nickel, molybdenum and boron in addition to zinc (Hearman 1938). Similarly Riceman and Anderson (1941) have reported that in the Robe area in South Australia the addition of zinc sulphate in the presence of applied copper, increased the grain yield of oats considerably.

Although the colour of the plants grown in the red soil was lighter than that of the black fallow soil plants, the dry weight per plant of the former was greatest. In the field, on the other hand, the yield on black ground is usually superior to that on red ground. This is due largely to the fact that the moisture holding capacity of red ground is not as great as that of the black, and plants in the former type of soil are consequently liable to suffer most from a lack of moisture. This limiting factor was eliminated in the greenhouse experiments.

The occurrence of "dead-heads" which is a common feature of red-ground crops in the Wimmera district (Plate XII., fig. 11) is also considered to be closely correlated with the moisture relations of the plants. They occur most commonly under dry conditions. Further reference is made to this aspect in the discussion later. It will suffice to state here that while no "dead-heads" developed in the plants in the greenhouse experiment, they were very prevalent in plants grown in the same season and soil under very dry field conditions.

No accurate quantitative determinations of the severity of root-rot lesions on the roots of the plants in the greenhouse experiments were possible. It was observed, however, that root

development was much superior in the plants receiving the mineral mixtures, which resulted in decreases in the apparent severity of the lesions

The significance of these results is discussed after a description of complementary field experiments

TABLE 8—RESULTS OF GREENHOUSE EXPERIMENTS 1940 SHOWING THE COMPARATIVE EFFECTS OF STERILIZATION AND MINERAL TREATMENT OF NHILL SOILS ON THE DRY WEIGHTS OF FREE GALLIPOLI WHEAT PLANTS GROWN THEREIN

Treatment	Black Fallow		Black Wheat Stubble		Red Fallow	
	Dry Weight per Plant Grams	Per centage Increase	Dry Weight per Plant Grams	Per centage Increase	Dry Weight per Plant Grams	Per-centage Increase
Unsterilised	0 328		0 119		0 823	
Unsterilised + Superphosphate 1 cwt per acre	0 437	33				
Unsterilised + Superphosphate 1½ cwt per acre			0 114	4*	0 834	1
Unsterilised + Mineral Mixture No 1	0 572	74				
Unsterilised + Mineral Mixture No 2	0 606	85				
Unsterilised + Mineral Mixture No 3	0 485	48				
Unsterilised + Mineral Mixture No 4			0 353	198		
Unsterilised + Mineral Mixture No 5			0 325	173		
Unsterilised + Mineral Mixture No 6			0 231	94		
Unsterilised + Mineral Mixture No 7					1 056	28
Unsterilised + Mineral Mixture No 8					1 073	30
Sterilised (steam)	0 801	144	0 608	411	1 544	88
Sterilised (formalin)	0 84	1 0				
Sterilised (steam) + Mineral Mixture No 3	1 014	209				
Difference for significance	0 117	36	0 074	62	0 211	26

* Decrease

NOTE —For compositions of Mineral Mixtures see Table 7

FIELD EXPERIMENTS 1938-40

On the farm of Mr C P Dahlenburg, Nhill, the effects of mineral treatments on the growth and disease reaction of wheat on black and red fallow ground and of oats on black wheat stubble soil have been studied during 1938-40 inclusive The experiments were intended to be complementary to the greenhouse work described above

Method

The various minerals were mixed with superphosphate in the desired proportions and applied with the drill at seeding time The compositions of the mineral mixtures used in each season are shown in Table 9, and tests in which they were included are indicated in Tables 10, 11, and 12

All plots were 0 0322 acres in area, and each treatment was replicated three or four times in randomized blocks

During the season, random samples of approximately 60 plants were obtained from each plot and were examined for the prevalence of root-rot lesions. For comparison purposes, two samples were taken from the black fallow experiments, the first just prior to heading and the other very shortly before harvest when the roots were becoming senile.

The examination took into account the number of lesions in relation to the root development and general vigour of each plant, which was then allotted points according to the following schedule:—Very severe, 5 points; severe, 4 points; moderate, 3 points; light, 2 points; very light, 1 point; and no lesions, nil. The root-rot index of the sample was then obtained as follows:—

$$\text{Root-rot Index} = \frac{\text{Total points scored}}{(\text{Total number of plants in sample}) \times 5} \times \frac{100}{1.}$$

The yields of either grain or hay were obtained at the end of each season.

Results.

In each season, particularly the early portion, certain of the mineral mixtures tested produced very much superior growth in both wheat and oats to that induced by zinc sulphate alone (Plate XI., fig. 8; Plate XII., fig. 12). The greatest increases occurred in oats on stubble. Unfavorable climatic conditions in the latter part of each season, however, adversely affected the growth of the mineral treated plants in relation to that of the other treatments.

During 1938 and 1940 drought conditions were experienced, and the plants which were most forward early in the season suffered most later from the continued dry weather. In 1938 practically all the oats on stubble died before reaching maturity, while in 1940 they were too short to cut. In 1939 a series of very severe frosts occurred just prior to and during the heading of the mineral treated plants (which were the first to mature) while the later plants not receiving the mixtures escaped serious injury.

For these reasons, the differences in the final yields obtained from the various treatments were not in accordance with the early and mid-season appearances induced by the treatments.

The results of these, and of numerous other experiments conducted by the Department, have shown the importance of the incidence of the spring rainfall and late frosts in relation to the time of heading and flowering of wheat, in determining both the apparent severity of root-rot lesions and the yield of the crop. It is a well established fact that plants at the flowering stage are conspicuously sensitive to drought (Loehwing 1940).

TABLE 9.—FIELD MINERAL TREATMENT EXPERIMENTS, NHILL, 1938-40, SHOWING COMPOSITIONS IN POUNDS PER ACRE OF MINERAL MIXTURES USED IN EACH SEASON.

—	Mixture Number													
	1.	2	3.	4	5.	6	7	8	9	10.	11.	12.	13.	14.
1938														
Superphosphate	112	112	112	112	112	112								
Sulphate of ammonia		56	56	56	56	36								
Zinc sulphate	15	15	15	15	15	15								
Manganese sulphate	20		20	20										
Magnesium sulphate	30	30	30	30										
Copper sulphate				2	4									
Borax				0·5										
Cobalt chloride						4								
1939														
Superphosphate	112	112	112	112	84	84	84	84	84	84	112			
Sulphate of ammonia	37	37	56	56	28	28	28	28	28	28	56			
Zinc sulphate	10	10	10	15	10	10	10	10	10	10				
Manganese sulphate	10	10	10	20	10	10	10	10	10	10	20			
Magnesium sulphate	10	10	10	30		10	10	10	10	10	30			
Copper sulphate	2	4	2	2	2	2	2	2	2	2	2			
Borax	0·5	1	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5			
Iron sulphate							10		10	10				
Cobalt chloride								2	2	2				
Potassium sulphate										10				
Sodium iodide										0·5				
Potassium bichromate										0·5				
Nickel chloride										0·5				
Ammonium molybdate										0·5				
Barium chloride										0·5				
Tin chloride										0·5				
1940														
Superphosphate	112	112	112	112	112	112	112	112	112	56	56	56	56	56
Sulphate of ammonia		28	28	28	28	28	28	56	56	56	56	56	56	56
Zinc sulphate	10	10	10	10	10	10	10	10	10		10		10	10
Manganese sulphate	10	10		10	10		10	10	10	10	10	10		10
Potassium sulphate	15		15	15	15		15	10	10	15	15	15	15	10
Copper sulphate					4		3	3	3			3		3
Iron sulphate						10	10	10	10					10
Magnesium sulphate							10	10	10					10
Cobalt chloride									2					
Ammonium molybdate									2					
Nickel sulphate									2					

In some seasons, the application of superphosphate to wheat on Wimmera black ground has increased the yield by as much as 100 per cent, yet in other seasons this treatment has had no significant effect on yield. The importance of weather conditions on the response of wheat to fertilizers has also been recognized by Russell and Sallans (1940) in their work on common root-rot.

The high yields obtained in 1940 on black fallow soil when the yearly rainfall was approximately 10 inches (half normal) of which only $5\frac{1}{4}$ inches fell during the growing period, are attributable to the conservation of soil moisture by sound cultural practices during the fallow period preceding sowing.

TABLE 10.—RESULTS OF MINERAL TREATMENT EXPERIMENTS WITH GHURKA WHEAT ON BLACK FALLOW SOIL, AT NHILL, DURING THE SEASONS 1938 TO 1940, SHOWING THE EFFECTS OF TREATMENTS ON THE ROOT-ROT INDEX AND YIELD.

Treatment per Acre.	1938.		1939.			1940.		
			Root Rot Index.			Root Rot Index.		
	Root Rot Index.	Yield, Bus./ac.	First Sample 30th August.	Second Sample 4th December.	Yield, Bus./ac.	First Sample 16th September.	Second Sample 9th December.	Yield Bus./ac.
Untreated	..	..	40·2	66·0	27·3	55·3	64·3	38·8
Superphosphate, 1 cwt ..	45·3	26·4	43·1	54·2	26·6	44·3	53·3	43·0
Superphosphate, 1 cwt. + Zinc sulphate, 5 lb.	38·2	28·9	..	..	..	..	..	..
Superphosphate, 1 cwt. + Zinc sulphate, 10 lb.	..	..	39·2	48·4	30·5	48·0	58·4	46·1
Superphosphate, 1 cwt + Zinc sulphate, 15 lb.	38·0	28·3	..	..	..	..	..	..
Superphosphate, 1 cwt. + Zinc sulphate, 30 lb.	39·3	28·0	..	..	..	..	..	..
Superphosphate, 1 cwt. + Brown Zinc dross, 15 lb ..	37·9	27·5	.	..	..	..	..	..
Superphosphate, 1 cwt + Sulphate ammonia, 37 lb . ..	..	..	38·2	53·5	28·4	..	..	..
Superphosphate, 1 cwt. + Sulphate ammonia, 37 lb + Zinc sulphate, 10 lb. . .	..	..	32·7	54·5	31·5	..	..	..
Superphosphate, 1 cwt. + Sulphate ammonia, 56 lb. + Zinc sulphate, 15 lb.	38·4	29·4	..	..	..	..	..	..
Superphosphate 1 cwt. + Sulphate ammonia 28 lb.	..	..	..	..	..	50·4	55·0	43·2
Superphosphate 1 cwt. + Sulphate ammonia 28 lb + Zinc sulphate 10 lb.	..	..	..	..	..	47·1	58·1	42·8
Mineral mixture No 1 .. .	40·4	27·6	34·4	54·6	28·8	48·6	57·5	42·1
Mineral Mixture No. 2	37·2	30·1	34·6	54·9	30·3	46·4	58·6	42·2
Mineral Mixture No. 3	36·5	30·3	33·8	56·7	29·0	46·7	37·9	43·0
Mineral Mixture No. 4	34·6	31·4	25·3	52·7	30·3	42·3	61·4	43·7
Mineral Mixture No. 5	38·5	28·4	39·3	51·0	28·9	49·1	60·7	45·1
Mineral Mixture No. 6	33·3	29·6	35·0	45·9	30·3	46·3	60·3	45·7
Mineral Mixture No. 7	..		31·0	53·0	30·8	46·9	52·1	43·5
Mineral Mixture No. 8	..	.	33·6	52·3	29·2	49·0	57·3	43·5
Mineral Mixture No. 9	..	..	33·3	47·3	28·1	53·5	57·5	43·0
Mineral Mixture No. 10 ..	..	..	34·6	46·1	29·1	..	..	..
Difference for significance ..	5·9	2·4	6 3	13 3	2·3	5·7	17·9	4·0

NOTE.—For compositions of the mineral mixtures used in each season, see Table 9.

WHEAT—BLACK FALLOW SOIL.

With regard to the wheat experiments on black fallow ground, it will be seen from Table 10 that certain of the treatments significantly decreased the severity of root-rot lesions and increased the yield, although as stated above the increases in yield were not as great as the early appearances of the plots would indicate. Owing to the adverse seasonal conditions experienced, the differences in yield due to applications of zinc sulphate in 1938, 1939, and 1940 were not comparable with those

obtained in the previous two seasons (Millikan 1938). Although all the mineral mixtures produced an improvement in growth over plants treated with superphosphate or superphosphate plus sulphate of ammonia only, the plants receiving the No. 4 mixture in 1938 and 1939 were outstanding in regard to both height and depth of colour, particularly during the early parts of both seasons.

The No. 4 mixture was also more effective than the treatment superphosphate plus sulphate of ammonia plus zinc sulphate, thus confirming the results of the greenhouse experiments to the effect that some minerals other than zinc are important in inducing improvements in growth on Wimmera black soil (Table 8). The latter treatment was superior to either superphosphate plus sulphate of ammonia or superphosphate plus zinc sulphate, a result similar to that of Vanterpool (1940) in connection with browning root-rot of cereals. He found that nitrogenous fertilizers were of little or no value when applied singly, but when the phosphorus deficiency had been rectified, nitrogenous applications gave a further beneficial response. This is of particular interest as browning root-rot associated with *Pythium sp.* occurs in Wimmera black soil.

During the stage when marked differences in growth were apparent, the severity of root-rot lesions on the plants showing marked responses to the mineral treatments was significantly reduced Samuel (1934) has made a similar observation in connection with the percentage of "take-all" infestation on manurial plots at the Waite Institute. High yield was associated with a small amount of take-all and vice versa.

The severity of lesions is evidently related to factors affecting the vigour of the plant; mineral treatment cannot make up for an inadequate rainfall, particularly immediately preceding and after heading. Such an inadequacy will seriously affect plant vigour and increase the apparent severity of root-rot damage. The deleterious effects of continued dry weather was relatively greatest in plants receiving mineral treatments which, earlier in the season, showed the greatest growth, and therefore had a greater normal water requirement than untreated plants. For this reason, treatments which were accompanied by a significant decrease in the root-rot index at the time of the first sampling before heading, produced no such change at the time of the second sampling shortly before harvest.

At this stage, when the grain was practically dead ripe and the roots were becoming senile, the root-rot index was much higher than that at the time of the first sample just prior to heading. It was considered unlikely, however, that this increase in the root-rot index at such a late stage in the life of the plant would, in itself, have any significant effect on yield.

A large number of lesions on the wheat roots were cultured at each sampling to determine the relative abundance of the fungi associated with them.

The following are the fungi which were isolated, in order of their relative abundance:—

1938—

Helminthosporium sativum, *Fusarium sp.*, *Fusarium culmorum*, *Dendryphium sp.* (Plate XI., fig. 10), *Ophiobolus graminis*, *Curvularia ramosa* and *Pythium sp.*

Eelworms (*Heterodera schachtii* and *Pratylenchus pratensis*) occurred to a limited extent

1939—

First Sampling, 20th August.

Pythium sp., *Phoma spp.*, *Stemphylium lanuginosum*, *Helminthosporium sativum*, *Curvularia ramosa*, *Fusarium culmorum*, and *Dendryphium sp.*

Second Sampling, 4th December.

Fusarium culmorum, *Dendryphium sp.*, *Fusarium sp.*, *Periconia circinata*, *Curvularia ramosa*, *Macrosporium sp.*, *Fusarium moniliforme*, var. *subglutinans*, *Fusarium scirpi*, var. *compactum*; *Helminthosporium sativum*; *Ophiobolus graminis*, *Rhizoctonia solani*, and *Wojnowicia graminis*.

Eelworms (*Heterodera schachtii* and *Pratylenchus pratensis*) also occurred to a limited extent.

1940—

First Sampling, 16th September.

Pythium sp., *Fusarium sp.*, *Fusarium culmorum*, *Dendryphium sp.*, *Ophiobolus graminis*, *Helminthosporium sativum*, *Fusarium scirpi*, var *compactum*, *Fusarium sp.*, *Stemphylium lanuginosum*, *Rhizoctonia solani*, and *Periconia circinata*

Second Sampling, 9th December.

Pythium sp., *Fusarium sp.*, *Dendryphium sp.*, *Fusarium culmorum*, *Periconia circinata*, *Sclerotium sp.*, *Helminthosporium sativum*, *Fusarium scirpi*, var. *compactum*, *Ophiobolus graminis*, *Alternaria sp.*, *Rhizoctonia solani*, *Fusarium moniliforme*, var. *subglutinans*, *Stemphylium lanuginosum*, and an undetermined sterile fungus.

Eelworms also occurred commonly

It will be seen that a complex succession of fungi was associated with the root-rot lesions. Simmonds and Ledingham (1937), Sprague (1938), and others have similarly reported that cereals may be attacked by a complex of soil-borne fungi, while Garrett (1936), Lal (1939) and others have found that a similar sequence of organisms to that reported above occurred in wheat plants affected with take-all following the invasion of the root by the primary parasite.

Entry of the fungi into the roots may be facilitated by eelworm attack or by the breaking, at more or less regular intervals, of the tissues of the young roots outside the vascular areas which has been frequently found to occur in wheat plants growing on Nhill black soil (Plate XI., fig. 9); similar symptoms have been observed on the sub-crown internode. The cause of this phenomenon is at

present unknown; it may, however, be related to the fact that this soil expands and contracts appreciably with changes in its moisture content.

It is also of interest to note that *Periconia circinata* also occurred among Glynne's (1939) isolations from wheat at Rothamstead.

The fungus, tentatively referred to *Dendryphium*, is believed to be previously unrecorded in pathological history. On potato-dextrose-agar it produces dense, dark olive green to black colonies with a lighter coloured aerial growth. Large chlamydospores of very variable shape occur freely, while conidia are produced very sparingly on the aerial mycelium. The latter are ovoid, dark, 4 to 9 celled, sometimes branched, $15\text{-}27\mu \times 7\text{-}10\mu$, acrogenous, usually solitary, very occasionally catenate on short geniculate conidiophores (Plate XI, fig. 10).

Wheat—Red Fallow Soil—The Wimmera red soils are lighter in texture, and poorer in some mineral nutrients, lime and organic matter than the black soil (Table 5) Their pH is in the vicinity of 6·5 to 7·0 as against about 8·3 for the black type. Although lighter, these red soils are not as easily worked as the black. They dry out readily, tend to set, and do not show the self-mulching properties of the black soils.

None of the treatments tested (Table 11) produced the same relative improvement in growth as was obtained on black ground, indicating that the red soil presents a problem different from that of the black ground. It is evident that the mineral treatments applied to date have not been suitable to its particular requirements This confirms the results of the greenhouse experiments shown in Tables 5 and 8. The results of analyses in Table 5 show some of the important differences in the mineral composition of plants grown on red and black soils respectively In Western Australia Teakle and Thomas (1939) have had a similar experience They found that mineral mixtures significantly depressed the yields of wheat on various soil types, although in one instance the mixture produced a deeper green colour in the early stages of growth

In 1939 a significant reduction in the root-rot index and a significant increase in yield was produced by a dressing of superphosphate 84 lb. + sulphate of ammonia 28 lb + zinc sulphate 10 lb. per acre.

In contrast with the experience in 1939, much higher root-rot indexes and lower yields were obtained from the red fallow plots than from those on black fallow ground in 1940. This is attributable to the much lower incidence of rainfall in the latter year, which obviously affected the plants on the light red soils to a much greater degree than those on the heavier, more moisture retentive, black soil. It was estimated that in 1940, nearly 50 per cent. of the plants grown on the red soil produced "dead heads", and the grain in the remainder was very light and pinched

TABLE 11 —RESULTS OF MINERAL TREATMENT EXPERIMENTS WITH GHURKA WHEAT ON RED FALLOW SOIL AT NHILL DURING 1939 AND 1940 SHOWING EFFECTS OF TREATMENTS ON THE ROOT ROT INDEX AND YIELD

Treatment per Acre.	Root Rot Index	Yield Bus /ac
1939	3rd November	
Superphosphate 84 lb	63 1	20 6
Superphosphate 84 lb + Zinc sulphate 10 lb	60 8	19 8
Superphosphate 84 lb + Sulphate ammonia 28 lb	66 9	19 2
Superphosphate 84 lb + Sulphate ammonia 28 lb + Zinc sulphate 10 lb	54 7	24 0
Mineral Mixture No 6	58 7	20 5
Mineral Mixture No 9	59 7	22 2
Difference for significance	4 5	3 9
1940	27th November	
Untreated	80 4	9 8
Superphosphate 1 cwt	89 2	11 8
Superphosphate 1 cwt + Zinc sulphate 10 lb	93 4	10 9
Superph sphate 1 cwt + s lphate ammonia 28 lb	98 9	12 1
Superphosphate 1 cwt + sulphate ammonia 28 lb + Zinc sulphate 10 lb	82 6	10 7
S iperphosphate 1 cwt + Sulphate ammonia 28 lb + copper sul phate 5 lb	84 2	11 0
Superphosphate 1 cwt + Sulphate ammonia 28 lb + Manganese sulph te 10 lb	90 3	9 3
Superphosphate 1 cwt + Sulphate amm nia 28 lb + Iron sulphate 10 lb	92 1	11 0
Mineral Mixture No 7	90 1	11 5
Difference for significance	7 7	0 7

NOTE —For compositions of mineral mixtures used in each season see Table 9

The lower root rot index of the untreated plants in 1940 was due to the fact that at the time of sampling which was very late in the season these plants were much more immature than those receiving the remaining treatments

The following fungi in order of their relative abundance were found to be associated with lesions on the roots of the wheat plants grown on red soil —

1939—

Fusarium culmorum *Fusarium moniliforme* *Fusarium scirpi* var *compactum* *Sclerotium* sp *Ophiobolus graminis* *Fusarium* sp *Phoma* sp *Curvularia ramosa* *Periconia circinata* *Alternaria* sp and an undetermined fungus

1940—

Fusarium culmorum *Fusarium scirpi* var *compactum* *Fusarium moniliforme* *Helminthosporium sativum* *Fusarium* sp *Curvularia ramosa* *Helminthosporium* sp *Sclerotium* sp *Ophiobolus graminis* and *Phoma* sp

Over 80 per cent. of the isolations consisted of either one of the first three *Fusarium* species listed above

Oats—Black Wheat Stubble Soil—Oat experiments on black wheat stubble soil were conducted during the seasons 1938 1940

inclusive, the varieties of oats used were —1938 and 1939 Mulga, 1940 Gidgee Severe drought conditions were experienced in 1938, and the majority of the oat plants died before reaching maturity Observations indicated, however that treatment with superphosphate 1 cwt + sulphate of ammonia 56 lb + zinc sulphate 15 lb per acre, and also mineral mixture No 4 (see Table 9 for composition) produced an appreciable improvement in growth in the early stages of development No response was observed from applications of superphosphate + zinc sulphate

Details of the treatments sown in 1939 and 1940 are shown in Table 12

TABLE 12—RESULTS OF MINERAL TREATMENT EXPERIMENTS WITH OATS GROWN ON BLACK WHEAT STUBBLE SOIL AT NHILL DURING 1939 AND 1940 SHOWING THE EFFECTS OF TREATMENTS ON THE ROOT ROT INDEX AND YIELD

Treatment per Acre	1939		1940 *
	Root Rot Index 2nd October	Hay Yield cwt /ac	Grain Yield bus /ac
Untreated	23 8	28 4	11 9
Superphosphate ½ cwt			12 3
Superphosphate 1 cwt	22 0	28 4	
Superphosphate 1 cwt + Zinc sulphate 10 lb	23 1	29 8	
Superphosphate 1 cwt + Zinc sulphate 40 lb	20 0	29 6	
Superphosphate 1 cwt + Sulphate ammonia 37 lb	23 3	33 5	
Superphosphate ½ cwt + Sulphate ammonia 56 lb			13 1
Superphosphate 1 cwt + Sulphate ammonia 37 lb + Zinc sulphate 10 lb	19 4	32 7	
Superphosphate ½ cwt + Sulphate ammonia 56 lb + Zinc sulphate 10 lb			13 5
Superphosphate ½ cwt + Sulphate ammonia 56 lb + Copper sulphate 5 lb			13 8
Superphosphate ½ cwt + Sulphate ammonia 56 lb + Manganese sulphate 10 lb			12 7
Mineral Mixture No 1	16 8	33 4	
Mineral Mixture No 4	16 8	37 9	
Mineral Mixture No 6	20 2	33 6	
Mineral Mixture No 8			14 1
Mineral Mixture No 9	21 9	31 6	14 0
Mineral Mixture No. 10	19 7	30 6	13 7
Mineral Mixture No 11	17 9	37 9	14 6
Mineral Mixture No 12			14 8
Mineral Mixture No 13			15 3
Mineral Mixture No 14			15 6
Difference for significance	6 0	2 5	2 0

* In 1940 only a composite sample for disease observation was obtained at harvest The root rot index of this sample was 43 1

† For compositions of the mineral mixtures used in each season see Table 9

Relatively greater differences in growth were induced between these treatments (Plate XII fig 12) on stubble and similar treatments on fallow These differences in growth were accompanied by significant decreases in the severity of root-rot lesions, and significant increases in the yield of hay or grain (Table 12)

The root-rot indices of the stubble oat samples were found to be considerably lower than those of the wheat plants grown on fallow. The significance of this is discussed below.

The following fungi, in order of their relative abundance, were found to be associated with lesions on the roots of oats obtained from these experiments:—

Dendryphium sp., Curvularia ramosa, Fusarium culmorum, Alternaria sp., and an undetermined sterile fungus.

Discussion.

The field mineral treatment experiments with wheat and oats afford confirmation of the results of the greenhouse mineral treatment experiments with Wimmera soil, in which, in some instances, improvements in growth approaching that produced by soil sterilization resulted from the application of certain mineral mixtures In view of this result, it is obvious that the beneficial effect of soil sterilization on plant growth is not attributable solely to the destruction of soil-borne plant parasites, but rather, as has been demonstrated in an earlier section of this paper, to the increase in the availability of plant nutrients. Evidence was thus obtained that other elements in addition to zinc may be of importance in stimulating the growth of cereals on Wimmera black soil. The stimulation induced by the application of these elements was greater on stubble than on fallow soil.

A fact of great significance is that the relative improvement in growth at harvest, induced by the mineral mixtures, has been much greater under greenhouse than under field conditions. It was evident that the soil moisture content had a governing influence on responses resulting from the application of such mixtures. While adequate soil moisture was at all times available to the greenhouse plants, the field plants, particularly early in the springs of 1938 and 1940, suffered periods of severe drought, the effects of which on the plants was dependent entirely on the relative growth and degrees of maturity induced by the various treatments. As the mineral treated plants always showed the greatest initial growth and earlier maturity, it was they which were most severely affected by periods of drought. Loehwing (1940) has stated that plants are very conspicuously sensitive to drought during the flowering period.

Mineral treatment has been much more effective in improving the growth of cereals on black than on red ground. The latter soil differs in important respects from black soil, some of which are evidently limiting factors in relation to the responses induced by such treatments as have been applied to date; the treatments applied must obviously be such as to meet the particular needs of the soil concerned.

The growth of wheat and oats on black wheat stubble soil in the Wimmera district is normally much inferior to that obtained with either wheat or oats on fallow. It is of significance, therefore, that the stubble oat root-rot indexes shown in Table 12 are very much lower than those obtained in the wheat treatments on fallow (Table 10). Another important fact is that the relative responses resulting from the application of certain nutritional treatments to wheat or oats on stubble have been relatively much greater than those induced by similar treatments in wheat on fallow. These results indicate that the poor growth on stubble is associated more with the inability of the plant to obtain an adequate supply of certain nutrients from the stubble soil than to the effects of a severe infestation of parasitic root-rot fungi. It must be emphasized that this conclusion applies for wheat as well as oats grown on Wimmera black wheat stubble soil, as the former cereal was used exclusively in the greenhouse experiments. The presence of wheat straw obviously did not increase the pathogenicity of soil-borne pathogens to the extent that they became a serious limiting factor to the growth of wheat on wheat stubble. This conclusion appears to be in contrast to that of Tyner (1940), who found that in greenhouse pathogenicity tests with *Ophiobolus graminis* and *Helminthosporium sativum* the development of disease on the basal parts of wheat seedlings was greatest in the presence of wheat straw compost, and least in oat straw composts. He concluded that a greater biological control of the pathogens resulted from the activities of micro-organisms associated with the decomposition of oat straw than wheat straw.

The number of micro-organisms is much greater in cropped than in fallow soil (Waksman 1931, Starkey 1931, Timonin 1940A). Penman and Rountree (1932) also found this to be so under Victorian conditions. They confirmed Starkey's observations to the effect that the growth of the crop interfered with the accumulation of nitrate in the soil, the cropped soil (after allowances for the nitrate in the crop itself) containing less nitrate than adjoining fallow soil. It has been suggested (Russell 1927), that one of the chief causes of the depressed nitrate content of cropped soils is its utilization by the increased population of soil organisms.

To this utilization of nitrate by organisms decomposing the soil organic matter is attributable the depression of nitrates which is a characteristic feature of Victorian stubble soils. This large population similarly builds into its thallus the other soil nutrients which are essential for its growth. After a period of fallow, during which the completion of the decomposition of the crop debris occurs, these nutrients are again rendered available to the plant through the autolysis of the organisms. The effect of fallowing, in this regard, is therefore similar in nature though

not in degree to that of soil sterilization. Starkey (1938) has found that fungus hyphae were abundant even in fallow soil. Therefore, the sterilization of such soils and the subsequent autolysis of these organisms renders further mineral nutrients available to the plant.

The above is considered to be the explanation of the much greater response obtained from the application of mineral mixtures to stubble than to fallow soils, and the increased availability of minerals and the relatively greater improvement in growth of stubble sown, as compared with fallow sown plants, which results from sterilization of these soils.

These conclusions suggest the concept that a soil organism may have a deleterious effect on plant growth as a result of its saprophytic existence in the rhizosphere. It would follow that this effect would be greatest where the available supply of any nutrients was normally close to the threshold value for satisfactory plant growth in that soil. References to specific instances in the literature, where the deleterious effect of soil saprophytic organisms has been demonstrated, were cited earlier in this paper. A very brief discussion of the possible effects of changes in the soil reaction on the competition for the soil minerals between the soil organisms and the plant was also made

In view of these results, it is considered that the question of the effects of stubble on the occurrence of root-rot disease requires further examination, as it has often been assumed that ploughing in of stubble favours the development of the disease. The above experiments have shown, however, that the poor growth of plants on stubble may be due to a large degree, to factors other than the direct effects of parasitic fungi Indeed, the antagonistic effects on root-rot fungi of the organisms associated with the decay of wheat stubble in the soil (Garrett 1934, Waksman 1937, Lal 1939, Sandford and Cormack 1940) may decrease very appreciably the virulence of root-rot fungi in such soil. On the other hand, this saprophytic flora may be the indirect cause of the poor growth of cereals on stubble soils due to its demands on the available soil minerals.

These conclusions may be important in areas such as the Victorian Mallee district where the ploughing in of wheat stubble is recommended in preference to "burning off" to help check the tendency of the soil to drift. Any immediate benefit that "burning off" may have over that of "ploughing in" of stubble may be due at least as much to the readily available mineral ash which is returned to the soil as a result of the former practice, as to any destruction of fungus inoculum. In this regard, the writer has often observed in the case of Wimmera black soils that a much better growth of stubble sown oats results on patches where the stubble straw has previously been raked into small heaps before burning.

It would seem from the results of these greenhouse and field experiments that deficiencies of, firstly, soil moisture, and secondly, available soil nutrients are of more importance than the direct effects of root-rot fungi in limiting the growth of cereals on Wimmera black soil under field conditions. Lack of adequate soil moisture has the greatest effect on the plant immediately prior to and during heading. Some of the principal effects of soil drought on the wheat plant have been discussed by Loehwing (1940) and Whiteside (1941).

There is no doubt that physiological disturbances in the plant, induced by adverse changes in the moisture and available nutrients of the soil, profoundly affect the apparent severity of root- and foot-rot disease. References relating to the relationship between mineral deficiencies and the disease have been cited earlier. It has been observed in Victoria that "dead heads" may be very prevalent in wheat grown on Wimmera red soil in seasons in which very dry weather is experienced These soils are lighter in texture than the black and have a lower moisture holding capacity. Similar observations on the effects of dry weather have been made by Schaffnit (1930), Machacek and Greaney (1935), Hynes (1937), Shen (1940), and others Under such conditions, the nutritional relationships of the plant are not good, and the direct effects of the associated fungi are of secondary importance when compared with the effects resulting from the occurrence of an unfavourable plant environment during a critical period in the development of the plant.

A somewhat similar conclusion has been arrived at by the Council for Scientific and Industrial Research (Anon. 1940). From experimental evidence it has expressed the tentative view that the "white-head" condition, which in the field often accompanies the presence of *Ophiobolus graminis* in the base of the wheat plant, is the expression of physiological trouble associated with the chemical composition of the soil. In this regard, it should be noted that striking results in the elimination of "dead heads" in wheat have been obtained by the application of copper sulphate to certain areas in Western Australia (Teakle et al 1941).

Such a condition is parallel to the occurrence of oat blast, which Johnson and Brown (1940) have demonstrated to be induced by any adverse influence on the normal nutritional condition of the oat plant, from the time the spikelets are initiated until just prior to the emergence of the panicle.

It has also been shown that adverse environmental factors immediately prior to and during heading may profoundly influence the response of cereals to fertilizer treatments.

The fact that the presence of parasitic fungi in the roots of cereals is often accompanied by more or less severe symptoms of disease in other parts of the plant does not necessarily mean,

therefore, that such symptoms are the direct result of the presence of the parasite in the roots of the plant. It has been shown that in some instances at least, they are more the outward expression of physiological disturbances in the plant induced by an unfavourable environment, than the results of the attack of parasitic organisms. Where the environment is favourable for plant growth, the presence of the root parasite may not have any observable effect on the growth and yield of the plant. Such a case has been recorded by Samuel and Greaney (1937). They isolated ***Fusarium culmorum*** from the roots of very healthy wheat plants in crops in various parts of England. Some of the isolations when tested out in the greenhouse proved pathogenic.

Similarly, the writer has freely isolated ***Fusarium culmorum***, ***Helminthosporium sativum***, ***Curvularia ramosa*** and a number of other fungi from the roots of otherwise healthy plants, growing in one instance in a crop which yielded almost 60 bushels per acre.

As Samuel and Greaney have pointed out, much work has been directed towards the status of such fungi as parasites, and that only recently has attention been paid to their status as weak secondary parasites. A full knowledge of the predisposing factors encouraging parasitic action is obviously essential to facilitate the solution of the problem of the control of foot- and root-rot diseases of cereals. The compilation of Beeson (1941) has shown the important influence of soil type on the mineral composition of plants. This aspect, as it affects the root-rot problem, has received little attention from pathologists.

The results of other research work relevant to the above conclusions have been exhaustively reviewed by Garrard and Lochhead (1938), Garrett (1939), Sandford (1939), and Simmonds (1939).

Root-rot of cereals, as it occurs in the Wimmera district of Victoria, cannot be regarded simply as due to the attack of a single organism, but rather to a complex of organisms. It follows from the foregoing that unless the physical, chemical, and biological conditions of the soils were comparable, the results of greenhouse pathogenicity tests with a fungus selected from a complex of foot- or root-rot fungi, would have little or no relation to the effects of the same organism under field conditions.

Summary.

Using purified synthetic nutrient solutions, the elements manganese, copper, zinc, and iron were found to be essential for the growth of three of the root-rot fungi occurring in Wimmera black soil, namely, ***Fusarium culmorum***, ***Helminthosporium sativum***, and ***Curvularia ramosa***.

Amino nitrogen improved the yields of *F. culmorum* and *C. ramosa*, but caused sectoring in *H. sativum*. The growth of the latter fungus was stimulated by the addition of vitamins B_1, C and nicotinic acid to the nutrient solution.

Steam sterilization of Wimmera black fallow soil resulted in a very appreciable improvement in the growth of wheat, but concomitantly exercised a deleterious effect on the response of the plants to the application of zinc sulphate. Analyses of the plants showed that this effect may actually be associated with an excess of zinc in the plant, as it was found that the calcium, potassium, phosphorus, manganese, zinc, copper and nitrogen in the soil had become more available to the plant as a result of the sterilization of the soil. The percentage of iron in the plants was reduced by sterilization. Similar changes in the availability of minerals resulted from the sterilization of Wimmera red fallow soil.

Steam sterilization had no effect on soil reaction. Formalin sterilization induced a similar or better improvement in growth to steam sterilization.

Comparative analyses of wheat plants grown on Wimmera black and red fallow soils respectively showed that on the latter type of soil the plants contained the highest phosphoric acid (P_2O_5), zinc and copper, and the lowest lime (CaO), potash (K_2O), iron and manganese percentages.

The zinc responsiveness of Wimmera black soil, which is destroyed by steam sterilization, can be re-established by inoculating such sterilized soil two months prior to sowing with bacteria normally occurring in unsterilized soil. The re-inoculation of sterilized black fallow soil with some of the fungi and bacteria normally present in unsterilized soil, or with 1 per cent. of unsterilized soil two months before sowing, had no significant effect on the mineral composition of the plants four weeks after germination, but decreased the percentages of phosphoric acid (P_2O_5), potash (K_2O), magnesia (MgO), zinc and manganese in the plant at eight weeks after germination.

At this time, however, the general nutritional level of the plants grown in the re-inoculated soil was still much higher than that of plants growing in unsterilized soil.

The increase in plant growth resulting from soil sterilization has been relatively much greater on Wimmera black wheat stubble soil than on comparable fallow soil. Similarly the responses to the application of mineral mixtures under both field and greenhouse conditions have been greater on black stubble soil than on fallow soil. During the growth of the plant up to the heading stage, the improvement induced by the addition of the mixtures to stubble soils under greenhouse conditions has in some instances been equal to or even better than that resulting from soil sterilization. After this stage the sterilized soil plants usually showed best growth.

It follows that the normally poor growth of oats or wheat obtained on Wimmera black stubble soils is attributable less to the occurrence of root-rot infection, than to the inability of the plant to obtain an adequate supply of nutrients from the stubble soil.

Whereas the inclusion of the elements magnesium, copper, cobalt, molybdenum, nickel and boron in the mixtures applied to black fallow soil significantly depressed the yield, their addition to the stubble soil mixtures caused an appreciable increase in the weight of dry matter produced. The process of fallowing Wimmera black soil evidently increases the availability of some at least of the elements listed above and renders undesirable the addition of further amounts of them to the soil.

These results suggest that soil-inhabiting organisms may effect the growth of the plant indirectly by using the soil nutrients for their own vital processes, thus reducing the amount available to the plant. The effects of this competition on plant growth would be most marked where the available supply of any particular nutrients normally approached the threshold value for satisfactory plant growth in that soil. This develops the concept that a soil organism may have a deleterious effect on plant growth because of its saprophytic existence in the rhizosphere.

Environment has an important effect on the nutritional requirements of the plant. Under greenhouse conditions the relative improvement in growth resulting from mineral treatment was greater than under field conditions where the incidence of rainfall in relation to heading was found to be of fundamental importance in determining the relative differences in yield induced by mineral treatment.

In the case of Wimmera red fallow soil the relative improvement in growth produced by the application of mineral mixtures was not as great as that obtained on black fallow soil, indicating that any mineral treatments applied must be such as to meet the particular needs of the soil concerned.

In the field, increased growth resulting from the application of mineral mixtures to wheat and oats on Wimmera black soil was accompanied by significant decreases in root-rot. Numerous fungi were associated with root-rot lesions on cereals in the Wimmera district of Victoria.

As the real effect of root-rot fungi on the growth of the plant may be considerably less than their apparent effect, it is of great importance to distinguish between symptoms caused by physiological disorders in the plant induced by unfavourable environmental factors and those caused by the direct effects of foot- and root-rot organisms. The alleviation of the physiological disorders will appreciably decrease the apparent severity of the foot- and root-rot diseases.

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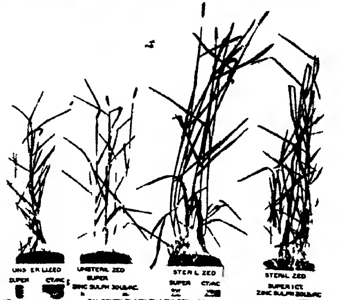
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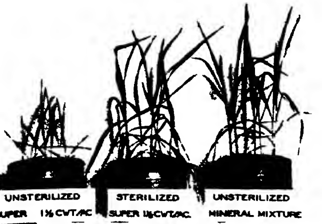
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NHILL BLACK STUBBLE SOIL 1939

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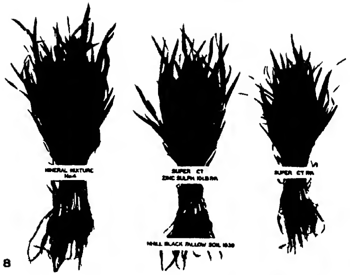

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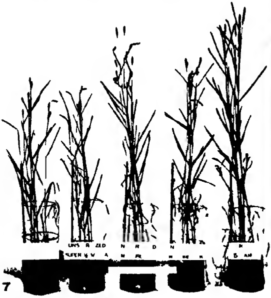

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Explanation of Plates.

PLATE X

FIG 4—Mineral deficiency experiment with *Curvularia ramosa* showing the appearance of the cultures after incubation for six days at 25°C

FIG 5—Showing the effects of soil sterilization and treatment with zinc sulphate respectively on the development of wheat grown in Wimmera black fallow soil at Burnley during 1938 Note improved growth due to soil sterilization Maturity stimulated by the zinc sulphate application to unsterilized soil and retarded by a similar treatment to sterilized soil

FIG 6—Showing comparative effects of soil sterilization and mineral treatment on growth of wheat on Wimmera black wheat stubble soil at Burnley during 1939 Photographed nine weeks after germination

PLATE XI

FIG 7—Showing the comparative effects of soil sterilization and mineral treatment on the growth of wheat on Wimmera red fallow soil at Burnley during 1940

FIG 8 Representative samples of plants obtained 12 weeks after germination from wheat experiment on black fallow soil at Nhill during 1939 Note very improved growth of the mineral mixture at this stage

FIG 9—Rootlet from wheat plant grown in Nhill black soil showing breaking at regular intervals of tissue outside the vascular area

FIG 10—Conidiophore and spore of a previously undescribed fungus tentatively referred to the genus *Dendryphium* which is commonly associated with root rot lesions on cereals grown in Wimmera black soil

PLATE XII

FIG 11— Dead heads in wheat growing on Wimmera red fallow soil

FIG 12—Representative samples of plants obtained 18 weeks after germination from the oat experiment sown at Nhill in 1939 on black wheat stubble soil Treatments as indicated Note the improvement in growth induced by Mineral Mixture No 4

[Proc. Roy. Soc. Victoria 54 (N.S.) Pt. II 1942]

Art. IX.—*The Heavy Minerals of Some Victorian Granitic Rocks*

By GEORGE BAKER, M.Sc.

[Read 13th November 1941; issued separately 31st August 1942.]

Introduction.

The heavy mineral assemblages and index numbers (ratio of heavy to light minerals by weight) of granitic rocks have been examined in considerable detail in other parts of the world during the past few years, but little work of this nature has hitherto been carried out with Victorian granitic rocks (see 1, 3, 4, 6 and 68). Over 100 Victorian granitic rocks were therefore selected for heavy mineral examination. The greater number of these are granites, and the total treated represents almost one half of the localities where granitic rocks occur in Victoria. Previously it was stated that most of the acid plutonic rocks of Victoria were granodiorites (66, p. 295), but outcrops of granite are more common than was originally thought, although the total areal distribution of granodiorites may be the greater.

Most Victorian granitic rocks occur as stocks or batholiths. Their distribution is shown on the accompanying map, the extent and shapes of the exposures being modified from the sixteen miles to one inch geological map of Victoria (1909).

The specimens examined were obtained from surface outcrops, and little field data is available regarding the levels in the intrusions that such positions represent. Attempts have been made to correlate certain of the Victorian granitic masses and to differentiate others. Only partial success has been obtained in correlation, as more often there are greater differences than similarities between the various granitic rocks. The heavy mineral investigations indicate the occurrence, distribution and concentration of the heavy accessory minerals in greater detail than can be obtained by the examination of thin sections of rocks. In thin sections heavy accessories are seldom sufficiently concentrated to permit comprehensive observations, and many are often not seen or are passed over. It has been said, for example, that sphene is generally absent from most Victorian granitic rocks (74, p. 33), but sphene has been found in the heavy mineral assemblages of over one third of the examples (see Table 5).

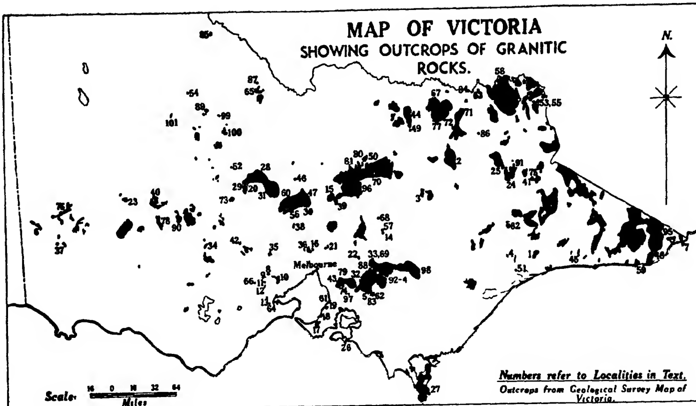

Fig 1

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Classification of the Granitic Rocks Examined.

The nomenclature of the granitic rocks is based mainly upon thin section investigations, accompanied in some instances by chemical and micrometric analyses carried out by previous workers. Specimens employed from hitherto undescribed outcrops have also been named from thin sections, aided in several instances by partial Rosiwal micrometric analyses (Table 1). The earlier nomenclature of a few examples has been modified in the light of more detailed examinations. Thus the Dromana stock, originally regarded as syenite (40) and later as granodiorite (49), proves to be a granite (3). The outcrop at Big Hill near Bendigo has been called granite (22), but the excess of plagioclase over orthoclase, and the high index number considered in conjunction with thin section examination, place it preferably with the granodiorites.

TABLE 1

Locality	Ratio of orthoclase to plagioclase
1 Upper Beaconsfield	1·0 : 2·3
2 Zumstein's Crossing, Grampians	1·0 : 1·6
3 Narre Warren	1·0 : 1·6
4 Kerrisdale	1·0 : 1·5
5 Oliver's Hill, Frankston	1·0 : 1·4
6 Mt Baw Baw	1·0 : 1·4
7 Big Hill, Bendigo	1·0 : 1·3
8 Gong Gong, Ballarat	1·0 : 1·3
9 Dromana	1·4 : 1·0
10 Terip Terip	1·8 : 1·0

The ratios of orthoclase to plagioclase for Nos. 2 to 8 in Table 1 are intermediate between the true granodiorites and the so-called adamellites according to Hatch's classification (36, p. 165), and the rocks should therefore be regarded as adamellites. Many other Victorian granitic rocks classed as granodiorites fall into a similar category, but as the term "adamellite" has been disallowed by the Petrological Nomenclature Committee, and as such rocks possess relatively high index numbers (see Table 5), it is preferred herein to classify them as granodiorites. In like manner, granitic rocks from Harcourt, Ingliston, Trawool (67) and Broadmeadows (65), previously classed as adamellites, should be classed with the granodiorites, unless as at Trawool (5), they prove to be contaminated granites. The original nomenclature of these four rocks is retained in this paper for present purposes, but the adopted scheme for the other granitic rocks is to regard those with excess of orthoclase as granites, and those with excess plagioclase as granodiorites.

The available micrometric and chemical analyses of Victorian granitic rocks, most of which have been examined for heavy minerals, are set out in the following tables (Tables 2 and 3) —

TABLE 2—TABLE OF MICROMETRIC ANALYSES OF SOME VICTORIAN GRANITIC ROCKS

	Granites				Granodiorites							
	1	2	3	4	5	6	7	8	9	10	11	12
Quartz	34 8	32 0	29 0	28 7	32 1	35 8	29 4	31 2	23 5	26 3	28 1	27 7
Orthoclase	33 9	34 7	34 1	34 8	15 1	21 7	17 6	16 3	17 4	6 6	12 4	23 3
Plagioclase	24 9	25 6	19 1	25 5	40 6	28 6	39 8	31 6	39 0	38 1	34 5	32 8
Biotite	4 3	5 7	6 5	8 8	7 2	11 4	12 2	15 6	15 5	27 9	24 0	12 1
Hornblende	1 5			1 3	5 2	0 1	0 6		4 6			2 [illegible]
Accessories	0 6	2 0		0 9		2 4	0 3	2 3		1 7	1 0	1 6
Cordierite			6 8									
Muscovite			3 6									

1—Diomana (3) 2—Powelltown (6) 3—Terip Terip (5) 4—You Yangs (1) 5—Mt Leinster (16) 6—Oliver Hill Frankston (3) 7—Mt Eliza (59) 8—Powelltown (6) 9—Upper Beaconsfield 10—Braemar House Macedon (25) 11—Warburton (25) 12—Mt Baw Baw

In Table 3 (and also in fig 2), *a* — *r* = granodiorites (including the so called adamellites), and *s* — *y* = granites

a Cavendish Heights Fortune Valley Lysterfield Hills
b Braemar (Clyde) House Macedon (60)
c—Scotchman's Creek Warburton (25)
d Omeo
e—Bulla (69)
f Yackandandah (68)
g Broadmeadows (65)
h Talbot Drive Marysville (3)
i Belgrave
j—Quarry Hill Moraig (F J Watson anal)
k—Heskct (60)
l—Mt Eliza Mornington Peninsula (59)
m—Tintaldra (28)
n—Mt Leinster (16)
p—Trawool (67)
q—Harcourt (67)
r—Ingliston (67)
s Lake Boga (T F Field anal)
t—Gabo Island (67)
u—Mt Buffalo (21)
v—Mt Mittamatite (28)
w—Dog Rocks Geelong (67)
y—Cape Woolamai (67)

From chemical analyses Tattam classifies the Yackandandah rock (Table 3, column "f") as granite (68, p 26) the sample from this district used in the heavy mineral analysis is classified as granodiorite because of the high index number, the high specific gravity and the mineralogical composition Both granite and granodiorite are recorded within a short distance of one another at Yackandandah (40, p 221) The Tintaldra rock (Table 3, column "m") is classed with the granodiorites on heavy mineral evidence, although it has been stated from chemical analysis that it is as distinct from the granodiorites proper as from the granites proper (28)

TABLE 3—CHEMICAL COMPOSITIONS OF SOME VICTORIAN GRANITIC ROCKS

	a.	b.	c	d	e.	f	g.	h	i
SiO_2 ..	63·61	64·04	64·87	65·59	66·13	67·25	67·75	67·07	67·27
Al_2O_3 ..	15·09	15·83	16·24	17·46	16·83	16·46	16·11	15·55	14·96
Fe_2O_3 ..	0·93	0·80	1·83	4·21	1·11	0·42	0·30	0·50	1·10
FeO ..	4·56	4·47	4·80	0·10	4·17	1·99	4·00	3·38	3·13
MgO ..	2·82	2·84	2·62	2·36	1·83	1·00	0·79	1·69	2·22
CaO ..	4·52	3·52	3·20	1·08	3·26	2·74	2·66	2·97	3·63
Na_2O ..	4·06	2·42	2·83	4·10	2·25	2·91	2·60	3·21	2·92
K_2O ..	2·66	2·90	2·49	2·80	3·14	5·64	3·42	3·80	3·22
H_2O ..	1·14	2·63	0·62	1·96	1·91	0·66	1·16	1·17	0·88
TiO_2 ..	0·90	0·80	0·73	n.d.	tr	0·40	0·85	0·61	0·59
MnO ..	tr	tr.	..	n.d.	0·07	0·02	tr	0·04	tr
P_2O_5 ..	0·18	0·18	0·16	n.d.	tr.	0·19	0·09	0·23	tr
Total ..	100·47	100·85	99·76	99·71	100·70	99·78	99·95	100·38	99·93
Specific Gravity	2·75	2·77	2·72	..	2·77	..	2·68	2·65	..
Index Number	18·48	19·62	19·88	..	10·71	16·07	9·42	16·74	..

	j	k	l	m	n	p.	q	r	s.	t	u	v	w.	y
SiO_2 ..	69·17	68·92	69·46	67·67	67·71	69·19	70·94	71·57	70·94	72·46	73·30	74·29	75·99	76·31
Al_2O_3 ..	15·95	15·28	15·33	14·50	15·10	13·45	13·99	13·58	16·14	13·46	13·84	12·90	13·10	13·09
Fe_2O_3 ..	0·88	0·80	0·07	0·87	2·12	2·71	0·35	1·18	0·21	1·16	0·82	1·16	0·57	0·41
FeO ..	3·64	3·30	1·80	3·78	0·29	2·78	3·02	2·19	1·30	2·09	1·22	1·04	0·61	1·07
MgO ..	1·12	1·64	2·07	2·21	0·16	1·06	0·80	1·07	0·45	0·49	0·82	tr	0·18	0·36
CaO ..	3·04	3·04	3·14	2·18	0·53	2·04	2·35	1·72	0·93	1·31	0·84	1·12	0·41	0·65
Na_2O ..	2·64	2·71	3·07	2·48	2·81	2·89	3·94	2·79	2·77	3·36	3·12	2·96	3·30	3·00
K_2O ..	3·07	2·93	3·96	3·42	5·25	3·94	3·66	4·38	6·40	4·06	4·89	5·32	5·27	4·76
H_2O ..	0·36	1·26	0·12	1·92	0·83	0·93	0·32	0·80	0·75	0·94	0·69	0·85	0·54	0·40
TiO_2 ..	0·77	0·70	n.d.	0·61	0·25	0·31	0·38	0·46	0·17	0·46	0·20	0·17	0·11	0·20
MnO ..	0·08	tr	n.d.	tr	0·01	0·14	.	0·09	tr.	0·13	0·15	tr	0·06	0·11
P_2O_5 ..	0·02	0·10	0·10	tr	.	0·18	tr	0·11	tr	tr.	0·08	tr.	tr	tr.
Total ..	100·69	100·75	99·72	99·54	100·87	99·89	99·95	100·21	100·06	99·99	99·97	99·80	100·16	100·43
Specific Gravity	2·66	2·69	2·69	2·71	2·64	2·07	2·68	2·66	2·64	2·64	2·64	2·01	2·62	2·64
Index Number	11·68	..	12·40	13·77	7·70	10·30	10·51	7·75	0·25	5·78	3·12	3·59	3·56	2·33

Heavy Mineral Content of the Granitic Rocks.

The heavy mineral assemblages, index numbers and specific gravities of the granitic rocks are set out in Table 5. In most instances, rocks with higher index numbers have greater specific gravities; exceptions are mainly attributable to alteration. It is found that the average specific gravities of the Victorian granitic rocks listed in Table 5 are lower than the averages for granites and granodiorites quoted by Daly (20, p. 47) :—

TABLE 4

	Range in Specific Gravities (Daly)	Range in Specific Gravities (Victoria)	Average Specific Gravities. (Daly)	Average Specific Gravities. (Victoria)
Granites .. .	2·516–2·809	2·53–2·60	2·667	2·62
Granodiorites .	2·668–2·785	2·58–2·76	2·716	2·67

Explanatory Notes on Table 5.

The heavy minerals listed in Table 5 were obtained by crushing representative rock from each locality, and separating in bromoform of 2·88 specific gravity (50, p. 40). The weight per cent. of the heavy minerals (i.e. the index number) was calculated from the weights of the light and heavy fractions. The index number for each granitic rock is not an absolute value, since despite care in sampling and crushing the rocks, clean separations into individual grains could not be always obtained, and during separation into light and heavy fractions in bromoform, larger fragments of light minerals sometimes carried up small attached fragments of the heavy minerals, and heavy minerals sometimes carried down fragments of light minerals. The index numbers obtained are useful for purposes of correlation and differentiation, however, because similar conditions were more or less maintained throughout the heavy mineral separations, and any slight discrepancies affect all the results to similar degrees.

The distribution of the heavy minerals is indicated in Table 5 by means of letters. Similar sets of letters are employed throughout the table, but only those assemblages with similar index numbers possess comparable amounts of any particular mineral species, when the letters are the same in each. For each assemblage *A* (very abundant) indicates a species which is dominantly present, *r* (rare) indicates 7 to 24 per 2,000 grains, and *V* (very rare) represents a species with 1 to 6 per 2,000 grains present. The letters *a, C* and *o* represent varying concentrations between the above extremes. This method of representing the mineral concentrations is only partially quantitative, and as Taylor has shown, has its limitations as inaccuracies may arise from personal

TABLE 5—TABLE OF HEAVY MINERAL INDICES AND ASSEMBLAGES

Numbers following locality names refer to positions of outcrops on the accompanying map of Victoria	GRANITES: BAIRNSDALE (30)	WOORDONOOK (100)	COLQUHOUN (18) [GREY VARIETY]	GLENROWAN (48)	BORUNG SOUTH (90)	COLQUHOUN (14) [RED VARIETY]	NAYOOK WEST (52)	BETHANGA (82)	WODONGA (84)	JUNCTION OF MITTA & BUNDARRAH R. (24)	CAPE WOOLAMAI (26)	MT WILLS (28)	MT EMU (34)	CAPE EVERARD (30)	MT BUFFALO (2)	HEATHCOTE (46) [N. CROSBANK 72]	MT LAR NE GERIN (80)	DROMANA (17)	DERGHOLM (8)	OOO ROCKS (13)	MT MITTAMATITE (53)	WANGARATTA (44)	PYRAMID HILL (56a) [EVEN GRAINED VARIETY]	SOUTH ANAKIES (9)	STAWELL (40)	GEMBROOK (32)	LONGWOOD (31)	CASTERTON (37)	MT KORONG (100)
	1	2	3	4	5	6	7	8	9	10		12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
ANATASE																													
ANDALUSITE		V																V	V			r	o			V			
APATITE COLOURLESS	V		V	V	V	V	o	r	V	o	C	o	o	o	o	r	o	o	C	r	V	V	V	C	o	C	C	C	o
" - PALE YELLOW-GREEN															V												r		V
" - [illegible]																	V												
" - PLEOCHROIC CORES											o				V		V	r	C						r	V			
BIOTITE	V	a	V	C	a	V	C	a	o	a	A	V	A	A	a	V	A	C	o	o	a	V	a	a	A	A	a	A	C
CASSITERITE																	o												
CHLORITE		V	C	a	r	a	a		C	o			V	r	C	A	C	o	r	r	o			r	o	C	o	o	a
CORUNDUM																a						r							
ENSTATITE																													o
EPIDOTE			o			C				V	o	V	V			o	o	r	o		C	V				V		C	o
FLUORITE	V			a		o	V		r	r					V						V						V		V
GARNET	o	C		C		o		V		C		a	V		o				V		C				C	V	r	V	V
GOLD						V												V											
HEMATITE	o		V			r				o	o		r				o		r			C					r		V
HORNBLENDE						V			V							o		C	r	V		V				V	V		
ILMENITE	o			o	V		o		V		V		V	V	V				r			o				r	o	r	V
LEUCOXENE	C	V		a	C		V							o	r	o					r	o							
MAGNETITE			V			o				C			V		r	C	C	C	C	r	a				r	a			C
[illegible]										V																			
RUTILE			V								V	V	V												V				
SPHENE				o			o	o									o	o	r	r	V					r		r	
SPINEL								V																					
SULPHIDES (PYRITE, CHALCOPYRITE)			V	C		r	a	r	r	V		V	V	V	C	V		a	r	V		o		r		V	V	V	r
TOPAZ													V												o				
TOURMALINE				o			V					o			V						V					V	C		
WHITE MICA	C	a	C		o	C	r	o		o		A	r	C	C	r	o		V	o			A	V	V	V		o	V
ZIRCON COLOURLESS	o	r	r	o		V	o	a	r	r	o		C	o	o	V	r	C	r	r	C	V	o	r	C	C	o	o	V
" - [illegible]	C	o	o	C	r	a	o	r	o	o	o		o	o	V	V	o	C	C	o	C	C	r	r	C	o	o	o	o
" - PALE YELLOW	o		V		V	V	V	V	V	o	V		V	V	o		r		V	o			V	o		r	r	C	V
" - [illegible]	o	V		a		V	r		V				V		r			o	o	r	V			V	r	r			V
" - [illegible]		V																V					V				V		
" - [illegible]							V													V				V		V			
XENOTIME					V											r	r	V								V			o
SPECIFIC GRAVITY	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
INDEX NUMBER	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

A - very abundant   a - abundant   C - common   o - occasional   r - rare   V - very rare

TABLE 5—TABLE OF HEAVY MINERAL INDICES AND ASSEMBLAGES—*continued*

GRANITES

Numbers following locality names refer to positions of outcrops on the accompanying map of Victoria	BUNYIP (52)	POWELLTOWN (58)	ANAKIES (8)	MAUDE (88)	CUROA (80)	BIG HILL LANCEFIELD [coarse grey variety]	BPR HGNHURST (87)	BARRABOOL HILLS (84)	PYRAMID HILL (88A) [porphyritic variety]	GABO ISLAND (7)	DARRIWIL (U)	BAYNTON (80)	TERIP TERIP (96)	MT HOPE (87)	LAKE BOGA (88B) [grey variety]	WILSONS PROMONTORY (87)	GENOA (85)	MT BEENAK (94)	TOWANG (2)	PYALONG (47)	MT WILLIAM (60) [Grampian Ranges]	STRATHBOGIE (70)	HARROW (76)	BUNG L (38)	BIG HILL LANCEFIELD [coarse white variety]	GARFIELD (83)	LAKE BOGA (88A) [pink variety]	TYNONG (8)	YOU YANGS (101)	MT WYCHEPROOF (94)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ACTINOLITE																		V											o	
ANATASE													V																	
ANDALUSITE																								V						
APATITE - COLOURLESS	o	C	o	o	o	C	r	o	o	o	C	C	C	C	o	C	o	o	C	C	C	C		o	C	C	r	C	o	V
" - PALE YELLOW GREEN				V	V				V			V	o	V		V	V			V	V	r		r					V	
" - BROWNISH													V					V											V	
" - PLEOCHROIC GREEN	V	V		V										V		V	r	V										r	V	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	a	A	a	A	A	A	A	A	A	r	a	A	A	A	a	A	A	A	a	A	A	A	A	A	A	A	r	A	A	V
[illegible]	C	o	o	o	C	o	C	C	C	o	o	C	o	C		o	a	o	o	C	a	o		V	o	o		o	r	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SPECIFIC GRAVITY	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

A-very abundant a-abundant C-common o occasional r rare V very rare X recorded in thin sections or in the field only.

TABLE 5—TABLE OF HEAVY MINERAL INDICES AND ASSEMBLAGES—*continued*

Numbers following locality names refer to positions of outcrops on the accompanying map of Victoria	ADAMELLITES				GRANODIORITES																				
	Inglis ton (35)	Broadmeadows (18)	Trawool (16)	Marysville (14)	Maldon (20)	Mt Martha (19)	Mt Leinster (41)	Zumstein's Crossing Grampians (23)	Oliver's Hill Frankston (81)	Kerrisdale (38)	Limestone Creek (78)	Gong Gong Ballarat (42)	Harcourt (31)	Bulla (36)	Orbost (48)	Mt Buller near Merrijig (3)	Morang (2)	Mt Eliza (18)	Big Hill Bendigo (28)	Ararat (79)	Baringhup (29)	Majorca (73)	Narre Warren (74)	Tintaldra (65)	Mt Erica (66)
	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84
Andalusite							X											V							
Apatite colourless	C	a	a	o	C	C	C	o	C	C	a	C	C	a	C	o	a	C	a	C	a	o	C	o	C
" – pale yellow green	V	r	r		r	V				r	V			o	V		V							V	
" corroded																				V					
" – telescoping cores								o											o		r				
Biotite	A	A	A	X	X	X	X	C	X	A	X	A	X	A	A	C	a	X	A	X	A	X	X	A	A
Brookite																									
Chlorite	a	o	V	r	C	V	o	r	o	C	C	C	C	A	o		o	o	o	o	o	r	C	a	o
Corundum	V																V								
Epidote		r		r			o		V	V	r	V	r		r	V			V	r		V	r		
Fluorite					V			V					V												
Garnet	r	V	o	o	V	V		V		C			V	o			o	o							
Gold		V																							
Hematite						r											r								a
Hornblende						o	o	C	r		C	r	V		C	A	o	a		a			o		V
Ilmenite	r	o				r			C	r		V	V	r	o	r	o	r		o			V	r	
Limonite				V		V		o		r						V		V							
Magnetite	V	V	V	V	r	r	o	a			a					a		V		a					
Molybdenite					C												V	V							
Orthite								V		V															
Rutile		o				V					a	o			o	o		o		o	V		o		
Sphene				r	V	V	r	o				o	o		o	o		o	V				o		V
Sulphides ([illegible])	r	o	V	V	r	r	V	V					o	r			o	V						a	
Tourmaline		V	V	r				V		o			V	C	V					V			V	C	
White mica		o	r		V					C			C	C						C				o	
Zircon – colourless	C	C	a	o	C	C	a	C	C	C	C	C	C	C	a	C	C	C	o	C	o	o	C	o	C
" – inclusions in	o	o	r	a	r	C	C	o	C	o	o	a	a	r	o	C	C	C	C	o	a	o	a	o	o
" – pale yellow		C	o	V	V	V		r		o	V		V	V			V		V	o	V	V	V	V	V
" – zoned	V			o	r	o			o		V	C	V	V	V	V	C	V	V	r	V	r	r	o	V
" – pyramidal	V	V						V													V			r	V
" – "torpedo" habit	V	V	r	o			V			r	V			C	r										
" – corroded								V		V				V		V		V							
Zoisite																									
Specific gravity	[illegible]	2.67	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.67	2.70	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.70	[illegible]	[illegible]	[illegible]	2.70	[illegible]	[illegible]	[illegible]
Index number	1.75	2.48	10.2[illegible]	7.02	2.40	7.8	7.70	7.72	[illegible]	[illegible]	9.47	[illegible]	10.[illegible]	8.7	22	[illegible]	1.[illegible]	18.48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.77	[illegible]

A – very abundant a – abundant C common o occasional r rare V very rare X recorded in thin sections or in the field only

TABLE 5—TABLE OF HEAVY MINERAL INDICES AND ASSEMBLAGES—*continued*

Numbers following locality names refer to positions in outcrops on the accompanying map of Victoria	GRANODIORITES																PORPHYRIES				APLITES			DIORITES	
	MT DRUMMER (48)	MT BALDHEAD (82)	SELBY (78)	TARNAGULLA (82)	YACKANDANDAH (71)	EVERTON (77)	MARYSVILLE (57)	POWELLTOWN (83)	MONBULK CREEK (43)	HEALESVILLE (22)	TAWONGA (86)	UPPER BEACONSFIELD (87)	BRAEMAR HOUSE MACEDON (39)	BEECHWORTH (72)	WARBURTON (33)	SMALL HILL BUCKRABANYULE (89)	MT TAYLOR (4)	BUXTON (66)	YOU YANGS (10B)	OROMANA (17B) [GRANOPHYRE]	WARBURTON (69)	YOU YANGS (10A)	STRATHBOGIES (30)	GRANITE FLAT (81)	BROMANA (17A)
	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109
ACTINOLITE							o					V							a						
ANATASE																		V							
ANDALUSITE																					a				
APATITE – COLOURLESS	o	o	C	a	C	C	o	C	C	C	C	C	C	C	C	C	o	o	C	o	r	V	V	o	o
" – PALE YELLOW GREEN									V	V						r	r								
" – COLOURED								V						V						r					
" – POLYCHROIC CORES	V			C			V	V	V																r
AUGITE																			r					C	
BIOTITE	a	A	A	A	A	a	A	A	A	r	o	A	A	A	A	A	a	a	A	C	a	A	o	a	C
CASSITERITE						X																			
CHLORITE	o	r		o	o	r	a	o		A	a	V	a	o	A	o		C	o	r	V	o	o		r
EPIDOTE	a	a			r	V				V	o		r	r			o							r	
FLUORITE						V											C								
GARNET				V	V			V		r					V		a	a							
HEMATITE						o							o			o		o				r			C
HORNBLENDE	A	a	A	a		a	o		a			a			r				C	o		r		A	A
HYPERSTHENE													r		a									a	
ILMENITE	V		V		V			V		o		o			a	r		C	C	C					o
LIMONITE								r					a				r		o	a		r			
MAGNETITE	a	a				o	V			r	C		C									r		a	
MOLYBDENITE						C																			
ORTHITE			V	V	V																				
RUTILE						V														r					
SILLIMANITE							X																		
SPHENE	a	o	C	o	o	C	r	V	r			V		C		o			o						r
SULPHIDES (PYR., PYRRH., CHALCOP.)	a	r			V	r	r	o	o	o			o	V	r		r		r					V	
TOURMALINE					V	X	V	V		r			V					o			r		A		
WHITE MICA	a	r		V						o	A	V		r		C					o		C		
ZIRCON – COLOURLESS	a	a	o	a	C	r	a	o	o	C	r	o	C	o	o	o	C	C	C	C	V	o	V	V	a
" – INCLUSIONS IN	o	o	o	C	r	r	o	o	o	r	o	o	o	o	r	r	V	V	a	o	r	o	r		o
" – PALE YELLOW		V						V					V		V	r		V		r	V		V		
" – ZONED		V	V	V		V		V	V					V	V				C	r		r			
" – PYRAMIDAL								V							V					V					
" – "TAPERED" HABIT								V		a	V				V	a					V				V
" – CORRODED								V					V		V				V		V				
ZOISITE	r							V			V		r		o		a							V	V
SPECIFIC GRAVITY	2.72	2.72	2.70	2.75	2.70	[illegible]	2.68	2.72	2.70	2.63	2.70	[illegible]	2.68	[illegible]	2.72	2.71	2.68	2.68	2.64	2.64	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
INDEX NUMBER	14.60	10.30	10.43	8.81	8.07	10.71	9.74	8.88	7.89	[illegible]	9.33	9.48	15.40	15.88	8.88	24.75	4.70	9.40	11.40	9.71	8.88	4.06	4.60	[illegible]	30.88

A–very abundant a–abundant C–common o–occasional r–rare V–very rare X–recorded in thin section or in the field only

errors when the minerals are classed into such categories (as in Table 5) by eye estimation, instead of by the method of counting grains (71, p. 687).

The letters accompanying similar numbers after the locality names at the head of the table, refer to different rock types from the same area.

The Grouping and Origin of the Heavy Minerals.

The heavy minerals are grouped into (A) heavy essential minerals, and (B) heavy accessory minerals. The heavy essential minerals are ferromagnesian silicates, which, because of their variation in granitic rocks, Marsden considers should be excluded when correlating such rocks by heavy mineral methods (47, p. 134). They are included here, however, because of their influence upon the index numbers, and because they are frequently of use in comparing and distinguishing isolated granitic outcrops. A sudden rise of index number in the granitic rocks is invariably due to increase in ferromagnesian minerals as has also been found by Groves (35, p. 472).

The heavy accessory minerals are those which are present in such small quantities that they are best studied by methods involving concentration rather than by thin section methods (76), and they have been subdivided into groups in Table 6 on their probable modes of origin. Combining the ideas relating to the genesis of the various heavy mineral species (51, 54, 72, 77, etc.), and using Wells' classification (73) as a basis, the heavy minerals obtained from Victorian granitic rocks are grouped as follows.

Table 6

A Heavy Essential Minerals—biotite, hornblende, white mica

B Heavy Accessory Minerals—

1 Normal or primary minerals (developed independently of a high flux content, and usually early products of crystallization)—
apatite, zircon, ilmenite, magnetite, rutile, gold, pyrite, pyrrhotite (and some sphene, orthite, andalusite and sillimanite)

2 Pneumatolytic minerals (developed by flux concentration, and formed late in the cooling history of a magma)—
tourmaline, topaz, fluorite, brookite, molybdenite, pyrite, anatase, cassiterite (and some rutile and apatite)

3 Products of Contamination (developed by the addition of foreign material and formed as products of assimilation or introduced as xenocrysts)—
andalusite, garnet, sillimanite, diopside, augite, corundum, hypersthene, actinolite, spinel (and some orthite and sphene).

4. Secondary minerals (produced by weathering or replacement, and formed at the expense of the primary minerals)—
epidote, zoisite chlorite, hematite, limonite, leucoxene (and some white mica and sphene).

This grouping has its limitations, because it is impossible to tell in contaminated granitic rocks how much of the biotite and hornblende is primary, and how much is due to contamination. Groves (33, p. 224), Brammall (10, p. 45), Stark and Barnes (64, p 348) and Grantham (32, p. 306), all regard a certain amount of the hornblende in granitic rocks examined by them

as being derived from the assimilation of foreign rocks. The author has indicated a similar mode of origin for some of the hornblende at the You Yangs (1) and at Dromana (3).

Biotite and hornblende have most effect on index number variation in Victorian granitic rocks. The hornblende is more abundant in granodiorites than in granites, and is usually subordinate to biotite, although in the Selby granodiorite, these two minerals are present in approximately equivalent proportions. High biotite content in the Victorian granitic rocks is usually accompanied by a low percentage of hornblende The paucity of these two minerals in one granite compared with another may mean that one is less contaminated.

White mica occurs in some of the granitic rocks as a primary constituent (muscovite) as at Springhurst, Mt. Korong, Lake Boga, Pyramid Hill, Mt Wills, Wooroonook and Mt. Wycheproof. In others, it is secondary and developed from the alteration of cordierite, or is bleached biotite

Among the heavy accessory minerals, sphene may be primary or secondary or a product of contamination, and the relative abundance of these types cannot be determined in the heavy assemblages or in thin sections. Groves (33, p. 224) and Wells (73, p. 260) concluded that much of the sphene in granitic rocks is due to assimilation, although Boos (8) and Brammall and Harwood (12) have described occurrences where it is secondary. Sphene is regarded as one of the chief diagnostic minerals in heavy residues by McAdams (48), but is not of such importance in Victorian granitic rocks on account of its threefold mode of origin (see Table 6). It occurs more commonly in granodiorites than in granites, and more abundantly in hornblende-rich types

The rare occurrences of gold in Victorian granitic rocks probably have a similar origin to those at Dartmoor, England, where scattered specks are regarded as primary (9, p 253). A pyrogenic origin is conceded for rutile at Dartmoor by Brammall and Harwood (11, p. 205). As there is no evidence of any other mode of origin of this mineral in Victorian rocks, it is classed with the primary accessories; it is as rare in Victorian as in British granitic rocks (33 and 46). Since anatase and brookite are regarded as having been formed during pneumatolysis (13, p. 22), they are here classified as pneumatolytic accessories as has been done by Wells (73) and Taylor (70). Anatase may be a secondary accessory, however, as shown by Smithson (61), but since both anatase and brookite are very rare in Victorian granitic rocks (see Table 5), only a few grains of anatase and one grain only of brookite having been noted throughout the assemblages, the mode of origin is indefinite.

The sulphide minerals occur in several groups of the heavy accessories in granitic rocks. In a few Victorian granitic rocks (e.g. Merrijig), pyrite along joint planes is of pneumatolytic

origin, likewise pyrrhotite in granodiorite from Morang. Widely scattered grains of pyrite in many of the granitic rocks are primary, being remote from any visible veins in rocks unaffected by pneumatolysis, and are thus comparable with occurrences in the Shap granite in England (32, p. 305).

Andalusite of both contamination (16, p. 225) and of pyrogenic origin (38), has been recorded in Victorian granitic rocks, while corundum is known in Victoria as a product of contamination at the You Yangs (1) and at Powelltown (6). Garnet in acid plutonic rocks has been regarded as a product of assimilation (1, 12, 24, 26, 37, 68 and 73), and it is therefore grouped here among the contamination accessory minerals although Brammall and Harwood record some garnet as primary (15, p. 52). Hypersthene has been recorded from Scottish granites as occurring under conditions that exclude contamination by basic rocks (46, p. 32), but is classed with contamination accessories in Victorian granitic rocks because where present it occurs as xenocrysts derived from the incorporation of dacite xenoliths. This mineral is primary, however, in a two-pyroxene quartz diorite from Granite Flat in Victoria (*27*).

Most of the orthite (allanite) in Victorian granitic rocks is of contamination origin, but some occurrences are probably primary (*2*). Spinel is grouped with the primary accessories by Niggli (52, p 15), but this genesis is considered from its occurrence in basic rather than in acid rocks, since spinel crystallizes from a magma low in silica. In granitic rocks, spinel is a contamination accessory mineral, developing near contacts with wall or roof rock (73), and meagre occurrences of this mineral as xenocrysts or as armoured relics associated with sillimanite in cordierite crystals (e.g. as in the Piper's Creek granite near Kyneton), are known in Victoria.

The method of grouping the remaining minerals in Tables 5 and 6 requires no further comment, since their modes of origin in the crystallization of granitic magmas are generally accepted.

Zircon is the most abundant and most widespread of all the accessories in Victorian granitic rocks, being equally developed in granites and granodiorites. Some varieties like the coloured, the zoned (14 and 19), and the corroded crystals (75), as well as those containing inclusions (17) and types with a "torpedo" habit (1 and 45), are listed in Table 5. In addition to these, rare acicular crystals occur at Powelltown (in the granite) and at Nayook West (6), distorted crystals (31 and 53) at Tynong and Mt. Beenak, parallel growths (34) at Cape Everard, Mt. Beenak, Longwood, Yackandandah and the You Yangs (1, p. 130, fig. 2D), pyramidal crystals and stout, stumpy crystals at Mt. Eliza, the You Yangs (1) and Oliver's Hill near Frankston, and rare crystals with outgrowths (18) at Gong Gong near Ballarat and Big Hill near Bendigo. Most of the zircons show

the normal crystal forms (110 and 111): rare rounded (water-worn) examples are probably xenocrysts.

Apatite is next in abundance to zircon among the primary accessory minerals. It is more common in granodiorites than in granites, and is frequently of greater abundance in hornblende-rich types. The presence of corroded crystals of apatite among the heavy mineral assemblages, indicates that apatite is sometimes attacked during the magmatic history of a rock (55, p. 218), and is therefore not as stable an accessory constituent of granitic rocks as suggested previously (33). In some assemblages, the occurrence of small apatites as clear rods and grains without inclusions, as well as fragments of larger crystals of apatite with few inclusions, and sometimes with corroded faces, may indicate two generations within the same rock. About a third of the granitic rocks examined contained apatite crystals with coloured (pleochroic) cores (4 and 62), and these are listed in Table 5 Apatite becomes subordinate in Victorian granitic rocks with increase of fluxes, and if present as a common constituent in the same rock as white mica, the latter is invariably the variety derived from the bleaching of biotite, as in the granodiorite from Tawonga.

Of the iron ore accessories, ilmenite is more common in the granodiorites than in the granites, but is never abundant in any one assemblage. Magnetite is less widely spread than ilmenite, but is more abundant in certain individual samples, especially hornblende-rich rocks Magnetite and ilmenite are never abundant together in the same assemblage, if one is common the other is subordinate or wanting.

A characteristic feature of the heavy mineral assemblages obtained from hornblende-rich granitic rocks is the marked occurrence of epidote, sphene, magnetite or ilmenite (usually magnetite), and greater quantities of apatite. This association is most pronounced among the heavy mineral assemblages of granodiorites in which hornblende is recorded as abundant or very abundant (see Table 5), and in which the index numbers exceed 11. Such granodiorites are therefore richer in lime and iron than the normal granodiorites, and the occurrence of epidote or secondary sphene, or both, indicates considerable late magmatic changes.

Pneumatolytic accessories in Victorian granitic rocks are more abundant and more varied in the granites than in the granodiorites, but no assemblage has a comparable wealth of pneumatolytic minerals as is contained in the Eskdale granite of Cumberland, England (56). They are regarded as next in importance to the stable primary accessory minerals for correlating granitic masses (33, p. 235). Tourmaline is the most widespread, being sufficiently common in a few examples to be classed as an auxiliary mineral (42, p. 28). Cassiterite was only recognized

in the assemblage of the Mt. Lar-Ne-Gerin granite, but has been recorded in the field from Everton (23, p. 15) and Wilson's Promontory (29 and 58). The remaining pneumatolytic accessories are confined to a limited number of Victorian granitic rocks, and are seldom well represented in any one.

Relationship of Index Number to Composition.

The relationship between index number and composition of chemically analysed Victorian granitic rocks is indicated in fig. 2, where the full circles represent granodiorites (including the so-called adamellites), and the full squares represent granites.

The results show a direct relationship between chemical composition and index number. FeO, TiO_2, CaO, MgO and Al_2O_3 increase with rise of index number while SiO_2 decreases. The index number is of value in the granitic rocks in providing quantitative data of the relationship between heavy (i.e. mostly ferromagnesian) and light (i.e. mostly quartz and felspar) minerals, and is regarded as useful for purposes of comparison or correlation, and for the detection of contamination and differentiation (33, p. 236). Consequently by reference to fig. 2, the heavy mineral index number provides a basis for estimating the approximate chemical composition of an unknown specimen.

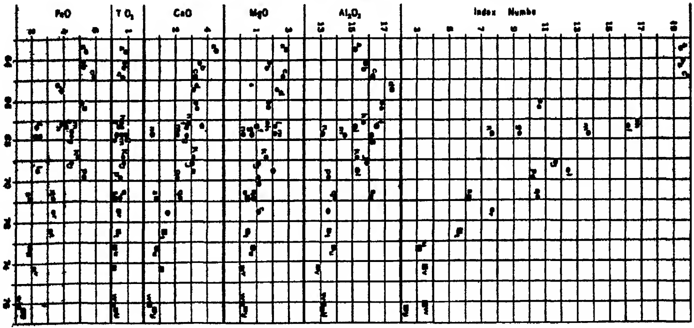
Range of Index Numbers of the Granitic Rocks.

The ranges in the index numbers of all the granitic rocks analysed by heavy mineral methods, are set out in fig. 3, where separation into different categories is based on the classification of the rocks from thin section studies, micrometric analyses and chemical analyses.

The range in the index number for aplites (2·1 — 4·3) is about centrally placed with respect to the range for normal granites (0·6 — 7); these are high values for aplites generally, because those examined are special types containing an abundance of andalusite or tourmaline. Normal aplites have smaller index numbers ranging as low or lower than the least value for the granites.

The index number increases as the normal granites pass laterally into a region of contaminated granites (7 — 13·5). Varieties of the granitic rocks originally regarded as adamellites have index numbers comparable with either those of contaminated granites or with those granodiorites with the lower index numbers. These so-called adamellites fall into a group representing transition types between true granites and granodiorites proper. The index numbers of the granodiorites are still higher and range towards, but do not reach the values for diorites. As in the granite group, higher index numbers result from contamination of the granodiorite magmas by assimilation of foreign material. The index numbers of two dioritic rocks included in

GRAPHS SHOWING THE RELATIONSHIP BETWEEN INDEX NUMBER AND CHEMICAL COMPOSITION (Letters on diagram refer to the same rocks as in Table 3)



[Page 811.]*

fig 3 show sudden increases upon the values for granodiorites owing to their greater percentages of essential primary ferro magnesian minerals

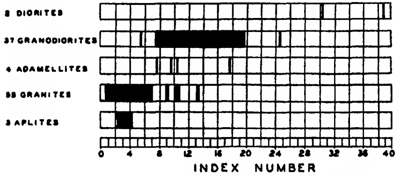


Fig 3—Diagrammatic representation of the range of index numbers of some Victorian granitic rocks

Index numbers over 7 in Victorian granites (e g You Yangs Tynong and Garfield) and over 15 in granodiorites (e g Powell town etc) indicate considerable contamination In the Buck rabanyule outcrop (index number = 25) for instance the high value of the index number is due to a local concentration of ferromagnesian minerals and is higher than in other parts of this intrusion It thus represents a contaminated portion (39 p 220) and has dioritic affinities Of the other contaminated granodiorites in Victoria that were investigated the index numbers do not reach 20 and there is thus a considerable gap between them and the lower figures for diorites Rocks with index numbers between 30 and 40 in Victorian igneous intrusions are true diorites

Deductions from the Heavy Mineral Analyses

Investigations by previous workers in the province of heavy minerals show that the nature of the heavy minerals and their distribution in granitic rocks depend upon such factors as the original composition of the magma the stage of differentiation attained the types of intruded country rocks and the amount of assimilation and sinking of contamination products A study of the heavy mineral suites of granitic masses therefore assists in determining whether granitic masses are comagmatic or unrelated to what extent they have been contaminated and in some instances what types of rocks were absorbed into the magmas Comagmatic masses should possess similar primary heavy minerals and higher index numbers would be obtained nearer the roofs of intrusions if appreciable assimilation had occurred and provided that sinking of contamination products was not great If heavy materials added to the granitic magmas

had sunk to any great extent, higher index numbers should occur in lower levels of the intrusions, although at depth, the attainment of equilibrium will probably have removed excesses such as those in evidence nearer contacts with country rock. The content of pneumatolytic heavy accessories, frequently missed in thin section examinations when scarce, indicates whether or not the intrusions were rich in mineralizers, but as fluxes concentrate near the roofs of intrusions, the absence of pneumatolytic accessories from any outcrop may be a direct consequence of deroofing, and therefore not then attributable to an original sparsity of mineralizers.

An examination of the effects of these processes upon those Victorian granitic rocks analysed by heavy mineral methods, results in the following observations:—

Contamination Effects.—The contamination of many Victorian granitic rocks is indicated by their content of xenoliths, by the occurrence of high index numbers, and by the presence of contamination accessory minerals. These three factors, although intimately dependent upon one another, are not necessarily all pronounced in the one rock type. Thus among the contamination accessories, the mineral garnet, although rare, is widespread in the heavy mineral assemblages of the Victorian granitic rocks, but all rocks with garnet do not have high index numbers (see Table 5). The prominence of ferromagnesian minerals in some examples results in increased index numbers, and although such granitic rocks may sometimes contain abundant xenoliths, heavy contamination minerals added to the magma may not be distinctive as such in the assemblages, since they may have been made over to mineral species comparable with those already crystallizing from the magma. In such examples, contamination results in the addition of unknown amounts of minerals like the ferromagnesian silicates. Even though some of the granitic rocks have low index numbers (see Table 5), and would therefore appear to be only slightly contaminated, several of them contain foreign xenoliths in various stages of mechanical disintegration and chemical digestion. Their low index numbers probably result from the continual removal of excess foreign material by convection currents within the magmas. In general, however, the granitic rocks with the greater index numbers contain more xenoliths than those with lower index numbers, except for special examples to be discussed later under Pneumatolysis. From xenoliths incorporated in the granitic magmas, minerals such as biotite, hornblende, sphene, orthite, garnet, diopside, augite, hypersthene, corundum, waterworn zircons, andalusite, sillimanite and iron ores are added to the magmas as xenocrysts by mechanical disintegration or as products of chemical digestion.

Some Victorian granitic rocks contain numerous xenoliths, some have fewer xenoliths but high index numbers (excluding those due to pneumatolysis), and others have contamination

accessories but low index numbers with few remnants of xenoliths. It is therefore concluded that the majority of them have been subjected to contamination by the addition of foreign material; some like the You Yangs, Tynong and Garfield granites to greater extents than others. Contamination is probably the main factor governing the variability of index number in Victorian granitic rocks.

Variation of index number within the same plutonic body is sometimes due to contamination by assimilation, as shown by Groves in the Channel Islands granites (33, p. 224). From present knowledge of heavy mineral relationships in Victorian intrusions, there is only one, the You Yangs granite (1), that shows evidence of greater assimilation at the margins and in higher portions. This is reflected in the index numbers which are generally greater at higher than at lower altitudes for central portions of the outcrop, and greater nearer the edge of the mass than in central parts at the same level

Differentiation Effects—Associated with contamination, the extent to which differentiation and sinking of earlier formed primary minerals or later formed contamination products have occurred also play an important part in the variation of index numbers and species represented in heavy mineral assemblages, both between different intrusions and within the confines of the same plutonic body The degree to which this factor has operated in the Victorian granitic rocks, cannot at present be gauged.

Pneumatolysis Effects—Flux concentration is sometimes an important factor in influencing index numbers and mineral assemblages in granitic rocks, and the occurrence of index numbers greater than the normal in granites, does not therefore always imply considerable contamination. In the Mt Wycheproof granite for instance, the index number (13·4) is 8·5 above the average (4·9) for Victorian granites, and is due to the abundant development of white mica of slightly greater specific gravity than that of bromoform in which the heavy mineral separation was carried out.

Pneumatolytic accessory minerals in the Victorian granitic rocks are usually of insufficient abundance to produce marked variations in their index numbers, although they are partially responsible for index number variations at Pyramid Hill and in the Futters Range.

Comparisons of Related Groups of Granitic Rocks.

The comparisons of the following groups of granitic rocks are based mainly on their heavy mineral assemblages and index numbers, but their appearance in the hand specimens, examinations of thin sections, and their micrometric and chemical analyses where available, as well as certain field characteristics in some instances, have also been taken into consideration.

Relationships of Separated Masses.

Similarities.—The most striking resemblances among separated outcrops of Victorian granitic rocks occur in the group of granodiorites associated with the dacite lavas of late Palaeozoic age in Central Victoria. Pronounced similarities in the heavy mineral assemblages exist between the granodiorites from Macedon, Healesville, Warburton, and Upper Beaconsfield, so that in support of other evidence (25, 26 and 43), the heavy mineral study of these types indicates development from a common magma and similarities in the intrusive histories. Allied types with somewhat lower index numbers at Monbulk Creek and Marysville have similar heavy mineral assemblages with minor variations.

Separated granitic masses that show some similarities occur in South-Central Victoria at Bulla, Morang, and Broadmeadows. The index numbers of these outcrops are comparable, and many of the heavy minerals are alike and about equally developed in each (see Table 5). In addition it has been stated that the Bulla and Broadmeadows rocks are associated chemically and mineralogically (41, p. 336). The occurrence of fresh and altered cordierite in both of these rocks indicates assimilation of similar rocks (Silurian shales). Similarities in these granodiorites suggests that they may be comagmatic, and any variations result from slight differences in the intrusive histories.

Earlier studies of thin sections and hand specimens of granodiorites led to the suggestion that similarities exist between outcrops at Macedon and Harcourt (60, p. 19), while the Mt. Eliza and Mt. Martha granodiorites are said to resemble the rock from Harcourt (44, p. 5). Although hand specimens of these rocks may superficially resemble one another, the examination of their index numbers and the variation in the heavy mineral assemblages (see Table 5) indicate that there are greater contrasts than similarities. The Harcourt rock (Mt. Alexander quarries portion), however, resembles the Bulla granodiorite in heavy mineral percentage, in the amounts and varieties of the primary accessories, and in the secondary minerals. Hand specimens are also alike, and the rocks at both localities contain xenoliths of sedimentary origin in similar stages of reconstitution.

Among some of the granitic rocks it is found that analogous index numbers occur for widely separated outcrops such as from Wilson's Promontory in the south and Mt. Hope in the north of Victoria, also granodiorites from Mt. Leinster in Eastern Victoria and Zumstein's Crossing in Western Victoria. Except for the total amounts of the heavy minerals being identical, there are no similarities in original composition for either the two granites or the two granodiorites.

Variations.—Outcrops of granite situated close to one another north-east of Geelong, show pronounced variations in the heavy

mineral assemblages and index numbers. The differences result from unequal amounts of de-roofing of the separated masses, and variations in the degree and nature of assimilation. The primary accessory minerals indicate that the separated outcrops are otherwise genetically related (1).

The neighbouring granitic masses in the Mornington Peninsula show variations in index numbers and heavy mineral assemblages as well as in other features. A study of these variations indicates that each of the outcrops at Oliver's Hill near Frankston, Mt. Eliza near Moorooduc, Mt. Martha and Arthur's Seat near Dromana had different intrusive histories, and that the main factors producing existing rock types were the degree of differentiation attained and the types of rocks assimilated into the magmas (3).

A group of neighbouring granitic outcrops in Western Victoria, at Mt. Lar-Ne-Gerin, Stawell, Ararat and Zumstein's Crossing, show wide divergences. Apart from the first two being granites and the other two granodiorites, they all differ in index numbers and mineral assemblages, as well as in appearance of hand specimens and thin sections. The conclusion is that all had different intrusive histories and were derived from different sources. In like manner, separated outcrops at Dergholm, Harrow, and Casterton in far Western Victoria bear little relationship to one another Outcrops at Bethanga and Wodonga in North-Eastern Victoria are not widely separated and have comparable index numbers The heavy mineral assemblages, however, contain significant differences such as the presence of certain mineral species in one which are absent from the other, and variable amounts of those species common to both (see Table 5). These variations indicate probable differences in the compositions of the original magmas and in the intrusive histories.

Relationships Within the Same Mass.

Similarities.—A number of samples selected from different localities in the Cobaw granitic massif in Central Victoria have closely analogous index numbers and heavy mineral assemblages. Samples from Mt. William, Baynton, Pyalong and two from Big Hill near Lancefield are all near the margin of the mass. They all have low index numbers which, in conjunction with the similar heavy mineral assemblages, rarity of xenoliths and other analogies, indicate that the exposure is a relatively uniform one. As pneumatolytic accessories are absent, the uniformity suggests that the Cobaw granitic mass has probably been subjected to extensive de-roofing, and a level in the intrusion has been reached where local excesses due to contamination have been removed. Minor variations exist, however, which must be attributed to slightly greater assimilation effects, the traces of which have not been eliminated by erosion. These minor variations are the occurrence of a larger index number for one of the Big Hill

samples, and the presence of local development of cordierite containing spinel in the Piper's Creek granite in the Kyneton district.

Variations.—In the batholith extending eastwards from Gembrook (6), samples from Powelltown, Bunyip and Gembrook have comparable index numbers and heavy mineral assemblages, but in the southern portion of the outcrop higher index numbers at Tynong and Garfield are due to greater assimilation of foreign material, and at these two localities xenoliths and basic schlieren are more abundant than in the other samples examined (2). Similar primary accessory minerals indicate that the original magma was uniform in character, but variations in the amounts of ferromagnesian minerals and in the distribution of xenolithic material, indicate different degrees of assimilation in different parts of the intrusion.

In the Strathbogies granitic mass, there is a general increase of index number in a southerly direction from Euroa (5·05) and Longwood (4·69) in the north, to Strathbogie (6·77) further south-east, and Kerrisdale (8·36) and Trawool (10·20) in the south-western extremity of the outcrop. At Terip Terip, east-north-east of Trawool, the index number is lower (6·07). Variations are due more to the amounts of each heavy mineral present than in the species represented, and as the primary accessories are similar, an originally uniform magma is indicated The abundance of cordierite in these rocks (5) supports the conclusion that contamination is responsible for the variable index numbers, and that assimilation of shales in large quantities has occurred over a wide area. Variability in the amounts of material assimilated has resulted in the formation of contaminated granites which in parts have distinctly granodioritic affinities as at Kerrisdale.

Similar variations in the same outcrop of granodiorite occur at Limestone Creek and Mt. Leinster where the mineral assemblages are similar but the index numbers differ, due to greater development of hornblende at Limestone Creek. In the Powelltown-Warburton mass of granodiorite, differences in the index numbers are due to variable amounts of biotite resulting from the assimilation of different rock types (6). Granodiorite at Mt. Erica (7), 20 miles east of the Powelltown-Warburton mass, and separated from it by a later granite intrusion, is probably comagmatic with the Powelltown and Warburton occurrence, because the primary minerals are identical. Variations in the index numbers and heavy mineral assemblages are due to divergences in the late magmatic history, when garnet and chlorite were formed at Powelltown and Warburton, while more hornblende than biotite was developed at Mt. Erica.

In the granodiorite mass of the Lysterfield Hills, south of the Dandenong dacites, different index numbers at Narre Warren (13·56), Selby (15·45), Monbulk Creek (17·29) and Upper

Beaconsfield (19·48) are due essentially to variations in the content of hornblende and biotite, most probably brought about by variable amounts of assimilation.

Samples of granodiorite from the granitic mass in which Harcourt is situated show considerable ranges in the index numbers but the heavy mineral species in rocks from Maldon, Baringhup, Harcourt and Big Hill south of Bendigo are generally comparable, the main differences being in the amounts of each present. The similar index numbers and heavy mineral assemblages of the granodiorite outcrop east of Majorca and that of the Baringhup area, indicate that the Majorca occurrence is comagmatic with the main Harcourt mass

In the Futters Range, the index number of the Wangaratta granite in the central portion is three times as great as that at Glenrowan in the south. The only common attributes of these two heavy mineral assemblages are the abundance of iron sulphides and the scarcity of apatite; the major variations in heavy mineral content can be gauged from columns 4 and 22 in Table 5. Although only eight or nine miles apart in the same mass, these two examples show considerable diversity in heavy mineral characteristics, mainly as a consequence of pneumatolysis.

Age Relationships of the Granitic Rocks.

Many of the Victorian granitic rocks are regarded as Devonian to post-Carboniferous in age (57 and 58). Some evidence of the relative age relationships of the granitic rocks of this period of magmatic activity can be obtained from their heavy mineral analyses. In the Cornish granites of England, Ghosh found that younger granitic types contained lower percentages of heavy minerals than older types (30). Where known intrusive contacts occur between older and younger granitic rocks in Victoria, a similar relationship is discovered. Thus at Tintaldra where granite invades granodioritic rock (28), at Powelltown where granite intrudes granodiorite (6), and at Pyramid Hill where even-grained granite invades porphyritic granite (39, p. 220), the younger intrusions possess the lower index numbers. At Mt. Korong where older and younger granites are recorded (74, p. 9), the index number for the older porphyritic type is 4·70; that for the younger, fine-grained intrusion is not available, but would probably be lower since it is described as having only a very small amount of biotite (74, p. 33).

Summary and Conclusions.

The heavy mineral analyses of over one hundred Victorian granitic rocks show that granodiorites have greater index numbers than most granites due principally to increased development of ferromagnesian minerals in the granodiorites. Some of the granites contain larger proportions of heavy minerals than others,

due to varied amounts of assimilation or of gas fluxing, resulting in increased index numbers which in some instances range up to the average index numbers for granodiorites. In like manner, granodiorites range towards the index number province of the diorites.

Evidence from the study of rock sections, chemical analyses, etc., of the granitic rocks subjected to heavy mineral analysis, indicates that rocks having index numbers below 7 can be grouped with the granites (an exception being that of the Maldon granodiorite), and those having index numbers above 10·5 (except where shown to be contaminated granites or to have been subjected to considerable gas fluxing) with the granodiorites. Seventeen examples with index numbers between 7 and 10·5, however, could not be specifically classed with either the granites or the granodiorites on heavy mineral analysis alone. The evidence supplied by their index numbers had to be supplemented by detailed thin section investigations and Rosiwal micrometric analyses. The results of the heavy mineral work in conjunction with other criteria, indicate that one of the granitic rocks (i.e. that from Trawool), previously referred to as adamellite, is better described as a contaminated granite, and the remainder as granodiorites. Thirty-three heavy mineral species are recorded, and the form and habit of some of them indicated.

The examination of the results of the heavy mineral analyses indicates that many of the Victorian granitic rocks have been contaminated by the assimilation of foreign material, some to greater extent than others, but little evidence of the part played by differentiation can be brought forward. Many of the magmas appear to have been relatively lean in mineralizers, because among the pneumatolytic minerals characteristic of wet magmas (beryl, tourmaline, monazite, fluorite, and cassiterite), beryl and monazite do not appear in the heavy mineral assemblages, and the others are relatively scarce, not being nearly so widely distributed and abundant as in certain of the English (31), Irish (62), and Scottish (46) granites. For this reason, most of the Victorian magmas would appear to have been dry magmas (63, p. 589), but it remains possible that many of the outcrops may represent low levels of erosion in the intrusive masses, where evidence of the existence of pneumatolytic minerals has been removed as a result of long continued de-roofing.

The correlation of or differentiation between the various granitic rocks in Victoria by means of heavy mineral index numbers and assemblages is found to be generally of greater value in small masses and over short distances in many of the larger masses than between masses that are widely separated. In many examples, differences in the heavy minerals reflect differences in the intrusive histories, but in others variations in

the primary accessory minerals point to different magmatic origins. Differences between widely separated masses are greater than similarities, but small outcrops close to one another in the field, or near to larger outcrops, are frequently found to be comagmatic with the neighbouring masses, according to the heavy mineral analyses. In the comparisons of the heavy mineral index numbers and assemblages for rock specimens from different localities in one and the same granitic mass, the heavy mineral analyses clearly show that some of the larger exposures are strikingly uniform in character, and the present surfaces might represent levels in the intrusions where contamination products have been so digested as to form a magma whose component parts were in equilibrium. In other instances, sets of heavy mineral analyses from one and the same outcrop show considerable variations, indicating probable closer proximity to the roofs of the intrusions and variable amounts of assimilation.

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ART. X.—*A Dome-like Structure in the Jurassic Rocks of South Gippsland.*

By A. B. EDWARDS, Ph.D., D.I.C.

[Read 11th December, 1941; issued separately, 31st August, 1942.]

The Jurassic sediments of South Gippsland outcrop chiefly in two north-east and south-west trending horsts, and in the intervening graben, which between them comprise the major portion of the South Gippsland Highlands (1). The detailed geology of the greater part of this region is shown on a scale of two inches to the mile on the Geological Parish Plans issued by the Geological Survey of Victoria. A study of these maps, and of the boring records published by the Mines Department of Victoria, reveals that the north-eastern part of the more southerly of the two highland areas is not a normal horst or tilted fault block such as is found elsewhere in the Highlands, but a large, elongated, dome-like structure, open to the south-west, as shown in fig. 1.

The Jurassic rocks in this part of the Highlands dip outwards in radial fashion, with dips ranging from 10 degrees to 30 degrees to the north-west, north, north-east, east and south-east from a central axis extending from Blackwarry south-westwards through Balook. The change in the direction of dip across the axis of the dome is relatively sudden, and it is only near Balook that the Jurassic strata do not appear to have undergone tilting. They are nowhere horizontal. This is partly because here, as elsewhere (2), the Jurassic strata had been folded into small, irregular domes and basins of shallow closure prior to the faulting and warping movements that gave rise to the larger structure under consideration. Where such undisturbed minor folds are exposed in section, they appear as closely-spaced, impersistent anticlines and synclines, with irregular strike directions; and since good exposures of the Jurassic rocks are found only in road and railway cuttings, and in the beds and cliffs of streams, most of the available dips in an undisturbed region show an exceedingly irregular arrangement of minor folds, as, for example, in the parishes making up the south-western portion of fig. 1. Such irregular folding may be taken as an indication that the region concerned has not suffered any marked later tilting. Where tilting or warping has occurred, it is superimposed on this earlier folding, and, if strong enough, tends to produce a prevailing, though fluctuating, dip in the direction of the tilt or warp. This is the case in the region now under consideration.

A further measure of the tilting and warping that has affected the South Gippsland Highlands is provided by the disposition of the Tertiary basalts and gravels that overlie the Jurassic at

many places The manner of occurrence of these Older Volcanic basalts was originally similar to that of the Newer Volcanic basalts forming the plains west of Melbourne The Older Volcanic basalts infilled valleys in the pre-basaltic land surface, and then formed a wide more or less horizontal, sheet covering the infilled valleys so that while the original under surface of the basalts was not level for structural purposes it approximated to a horizontal surface Warping or tilting of this approximately horizontal surface is readily detected from the disposition of the basalt residuals in any given area This may be seen for example, from the Geological Parish Plan of Moe where the main area of basalt slopes southwards at about 1 in 40 while along the Yarragon Scarp the same basalts have been tilted steeply to the north (3)

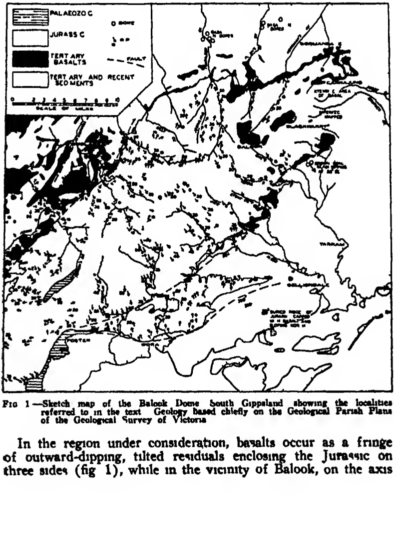

FIG 1—Sketch map of the Balook Dome South Gippsland showing the localities referred to in the text Geology based chiefly on the Geological Parish Plans of the Geological Survey of Victoria

In the region under consideration, basalts occur as a fringe of outward-dipping, tilted residuals enclosing the Jurassic on three sides (fig 1), while in the vicinity of Balook, on the axis

of the dome, they form a horizontal residual, overlying bedded gravels. Between Blackwarry and Carrajung are further residuals which show a gentle slope to the north-east. The disposition of the basalt thus provides clear evidence of the dome-like form of the structure.

This dome-like structure, which may be described for convenience as the Balook Dome, is marked off from the plains to the north and south by scarps, which have been attributed tentatively to faulting (1), the Carrajung Fault on the north, and the Won Wron Fault on the south-east. The records of bores put down in the adjacent Brown Coal areas indicate, however, that the scarps arise from warps, or relatively gentle monoclinal folds, rather than from faults, although these folds appear to pass into faults when traced to the south-west.

Along the northern flank of the structure, bores in the parishes of Traralgon, Loy Yang and Tong Bong (4, 5), show tilted basalt and overlying brown coal seams at first passing slowly to increasing depths, and then flattening. The basalt has been traced in the bores for a distance of nearly two miles north of where it ceases to outcrop, with a downward slope of only two or three degrees The position of these bores is shown on fig. 1, but it is possible that the basalt may continue further north, since the bores in that part of the area have not penetrated sufficiently deeply to establish its absence.

Along the south-eastern margin of the Balook Dome, most of the bores on the plains are too shallow to penetrate through the outwash sands to the underlying basalt, but in the Parish of Won Wron, a series of bores have revealed a seam of brown coal about 100 feet thick, which overlies the tilted basalt, and dips to the south-east at an angle to about 20 degrees beneath a mantle of outwash material (6). Further to the south-east the Tertiary beds presumably become horizontal again, since marine Miocene beds which are exposed in a large washout on Bruthen Creek, several miles above Woodside township, are horizontally disposed. While it is not known that the brown coal passes under this actual outcrop, related brown coals underlie similar Miocene beds at considerable depths in bores along Merriman's Creek, some miles to the north. The evidence at Hedley indicates that the faulting and warping movements here described are of post-Pliocene age (7), and no evidence has been found to suggest that any earlier Tertiary earth movements have affected the area.

Origin of the Structure.

When the northern monocline is traced south-westwards, it passes into a definite fault somewhere in the vicinity of Boolarra. From the evidence available, the actual point of transition cannot be fixed, but the change from irregular dips along Middle Creek, to a prevailing northerly dip further to the north-east,

suggests that the fault extends as far north as the point where Middle Creek leaves the scarp. The marked increase in the width of the basalt areas north-east from Billy Creek also points to the transition occurring near this point. The southerly monocline appears to continue as such until it is west of the Albert River, where a certain amount of minor folding is associated with it. From this point it begins to converge on the well-marked Gelliondale Fault, the two approaching each other in the vicinity of Foster, as shown in fig. 1. Certain other smaller faults shown by Hills (1), and on the Geological Parish Plan of Toora, appear to be non-existent. Between the Albert River and Foster the southerly monocline passes into a fault, and pronounced drag is shown in the Jurassic strata exposed along the east-west section of the Franklin River, where dips as great as 80 degrees south are found. The Toora Fault Block, lying between the Gelliondale Fault to the south and this Won Wron Fault and Monocline to the north, is tilted to the north at an angle of about 5 degrees (the steepest dips on this block rarely exceed 25 degrees north), and several small areas of basalt, overlain by Tertiary sands and gravels, are preserved on this block, close to the fault angle between it and the main horst to the north.

The Toora Block is much narrower than the main highland block, and much lower, so that the Agnes River and the Franklin River, having turned and followed the fault angle for some distance, were able to escape over the Toora Block to the south. Where they cross its scarp, they have developed prominent waterfalls with gorges downstream, from which they emerge to the narrow coastal plain on the downthrow side of the Gelliondale Fault. Both these rivers turn eastwards along the fault angle, suggesting that it sloped to the east, and the southern Billy Creek also flows along the fault angle in this direction, further to the east. There does not appear to have been any connexion between these streams.

Basalts outcrop alongside the Agnes River, south of the Toora Block; and in the Parishes of Alberton West, Welshpool and Toora, a number of bores have penetrated to the Jurassic of the downfaulted block south of the Gelliondale Fault (4) (5). The Jurassic rocks in the bores are capped in places by Tertiary basalts (6), and occur as a ridge whose surface slopes to the north at about 1 in 15, and rises to within a few feet of the surface near the central part of Alberton West (fig. 1). The failure of the Jurassic rocks to outcrop south of this point suggests that another step-fault, more or less parallel to the Gelliondale Fault, may exist in this vicinity.

Not only do the monoclines pass into faults when traced westwards, but the thickness of the Jurassic rocks decreases in this direction, and Palaeozoic sediments are exposed in the vicinity of Foster and Toora in the south, at Turton's Creek in the centre

of the horst, and north-east of Boolarra, near its north-western margin (fig 1). It seems possible that the change from warping to faulting in the Jurassic rocks is related to this decrease in thickness. Faults which developed in the Palaeozoic basement continued upwards through the Jurassic rocks where they formed a relatively thin cover over the Palaeozoic sediments; but further eastwards, as the thickness of the Jurassic sediments increased, and the amount of fault movement decreased, the faults died out upwards into monoclinal sags; and owing to the relatively strong nature of the Jurassic strata, the sagging was spread over a considerable horizontal area, thus giving rise to a dome-like structure opening to the south-west.

Drainage

The main streams of the domed region—Middle Creek, Northern Billy Creek, Jeeralang Creek, Traralgon Creek, Flynn's Creek, Merriman's Creek, Reedy Creek, Bruthen Creek, Mac's Creek, Tarra River, Stony Creek, Jack Rivulet, and Albert River, appear to be consequent streams, developed after the warping, so that they radiate from the central axis of the dome (fig. 1). They are all dip-streams over most of their courses, and this character is reflected in the frequent rapids and cascades that occur where the stream beds coincide with the surfaces of beds of hard sandstone Their valleys are deep, and steep sided.

In places along the axis of the dome, as on the basalt area near Balook, and along the upper stretches of some of the main interfluves between the radial streams, dissection has progressed relatively slowly, giving rise to upland areas whose shallow valleys are in striking contrast to those of the deeply dissected marginal areas of the dome The transition from the uplands to the deeply dissected country is often abrupt, and the upland streams frequently join the tributaries of the main streams across waterfalls.

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ART. XI.—*Further Observations on Rose Wilt Virus.*

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A disease of rose plants the primary symptom of which suggested the name "Rose Wilt" and the secondary symptoms the name "Rose Dieback" was shown in an earlier paper (Grieve, 1931) to be a sap transmissable virus disease It was pointed out then that the disease assumed epidemic proportions only at considerable intervals and as a consequence no continuous study of it has been found possible. This paper, however, presents the results of some further observations and experiments. Since the writer's original paper appeared, three other virus diseases of rose plants have been described one of which has many features in common with Rose Wilt.

REVIEW OF EXTERNAL SYMPTOMS OF ROSE WILT.

Little modification of the original description of the disease is necessary, but it appears desirable to restate in summary form the symptom picture. The recurving or epinasty of the individual leaflets on an infected shoot so that they give the appearance of being closely balled together is a constant feature of considerable diagnostic value (Plate XIII., fig. 1). This abnormal condition of the infected leaves persists as long as they remain on the plant. With this reflexing of leaflets is associated a condition of increasing brittleness of the laminae Abscission occurs very easily on touching or under the action of a gust of wind. On a badly infected plant complete defoliation may occur quite early, but generally a proportion of the recurved leaves remain attached for some time (Plate XIII., fig 3). External lesions have not been observed in young leaves in the reflexed stage, but occasionally, when affected leaves remain on the plant, reddish-brown, bordered, necrotic spots appear on the leaves. The dying back of the young shoots subsequent to defoliation proceeds quite rapidly in many cases and within a few days the plant presents a scorched and blackened appearance. Where more mature shoots are affected, dying back proceeds more slowly and a mottled appearance is produced on the affected canes by the presence of brown to black areas interspersed with areas where the original green colour of the cane is retained. The discoloured areas become larger and coalesce until finally the whole shoot is quite

discoloured and black. It has frequently been observed that oval green patches remain surrounding the buds on the canes for some time after the rest of the cane is blackened.

In plants which in one season suffer only a mild attack, the leaves may show only slight recurving and defoliation does not occur. Flowers come to bloom on such plants and these flowers show no traces of deformation Observation on such infected plants over two to three seasons has shown that the disease remains in them and may become serious in following seasons. On thick canes of these plants, reddish, somewhat raised areas are frequently scattered. It is of interest to note that the curious reflexing of the leaflets of virus-infected rose plants is paralleled by the effect on rose plants of ethylene gas (Zimmerman, Hitchcock, and Crocker, 1931), and to some degree also of a growth substance, β-indole-acetic acid (Grieve, unpublished data).

Experiments on the relation of auxin to epinastic response in several plants indicate that this growth movement is associated with a greater concentration of hormone toward the upper sides of the petioles It appears probable in the case of Rose Wilt that one of the initial effects of the virus is to cause some similar disturbance in hormone concentration at the bases of the leaflets.

INTERNAL SYMPTOMS.—HISTOLOGICAL CHANGES.

The internal symptoms associated with Rose Wilt have not previously been described, consequently the morbid anatomy of infected plants will be treated in some detail.

Examination of fresh stem sections of infected plants showed abnormalities of the cortical tissues and of the phloem similar to those which have been demonstrated in certain other viruses, such as Acropetal Necrosis of potato and Potato Leaf Roll.

Material for examination was fixed in Fleming's or Glacial acetic acid fixative, dehydrated and embedded in paraffin. Sections were cut at various thicknesses from 3 to 10μ. Haidenhain's iron alum haematoxylin with eosin counter stain, Fleming's triple stain and Safranin and Light Green were used for staining.

Healthy Stem.

For purposes of comparison a short account of a transverse section of a healthy rose shoot is here given. The stem is bounded by a single epidermal layer with a well-defined cuticle, beneath which there is a single sub-epidermal layer of fairly regular cells. The cortex consists of two types of cells, collenchymatous and parenchymatous. The collenchyma, which occurs beneath the sub-epidermal layer comprises a region varying from three to five cells in thickness. Many of these cells contain large deposits of tannin. The parenchyma zone is wider and consists of cells which vary from oval to rectangular in cross-section. The

innermost layer of the cortex bounding the stele was not found to differ in structure or size from the other cells of the inner cortex, but iodine staining showed it to be rich in starch and it may be considered as the endodermis. Within this endodermis is the pericycle which appears to be discontinuous: opposite each bundle it consists of several rows of thick-walled tightly-packed cells, while where the medullary rays pass out, the cells are parenchymatous. The vascular bundles are well defined and show considerable variation in size, both in a radial and in a tangential direction. The wood consists of vessels, tracheids and wood parenchyma; the phloem of sieve tubes and companion cells. The central part of the stem is composed of pith, two types of cell being present. Small thick-walled cells are found occurring in groups of two to five interspersed between much larger thin-walled cells. In the young shoots cambial activity is visible at an early stage and there is present secondary xylem and secondary phloem.

Rose Wilt Infected Stem.

Sections of shoots taken near the bases of reflexing leaves frequently showed as a first pathological condition the presence of considerable deposits of a brown gummy substance in and around the vessels. Slightly later, while the recurved leaves were still present on the cane, sections of petiole bases and of shoots showed necrosis of cells of the inner cortex, of medullary ray cells, and of a few cells of the secondary phloem. Affected cells in the cortical region were mainly opposite the bundles, but necrosed cells were also observed scattered through the cortex. Cells of the primary medullary rays were mainly affected in groups between the pericyclic fibres of contiguous bundles. The symptoms in these cells consisted of thickening and yellowing of the cell walls. Yellow gum-like deposits were present in necrosed cells.

At a slightly later stage when defoliation was commencing, sections of shoots showed greater necrosis of the phloem, the symptoms being thickening of the cell walls of the secondary phloem elements followed by the crinkling and collapse of cells (see Plate XIV., fig. 5, and text fig. 1). Owing to separation of cells from one another large intercellular spaces developed. Gum deposits were present in some of the affected cells and in the intercellular spaces.

Staining reactions indicated that the walls of affected cells were suberized while the deposits in the cells and intercellular spaces were gum-like. A red colour in the walls was obtained using Sudan III. and some of the deposits also showed a red colour. The necrotic regions resisted treatment by concentrated sulphuric acid. Tests with phloroglucin and hydrochloric acid gave negative results for lignin in necrosed cells; it was present in healthy cells of the collenchyma region of the cortex, the

thick-walled pericycle and the xylem. Sections of diseased tissue stained with iodine revealed a difference from healthy stems in that the endodermis contained little or no starch. Sections through shoots in which the dieback stage was commencing showed more severe necrosis in the epidermal and cortical cells as well as in the phloem. The necroses in the epidermal cells were associated with the discolouration visible externally at this stage. In some cases it was observed that necrotic cells could be traced from the epidermis to the pith via the primary medullary rays.

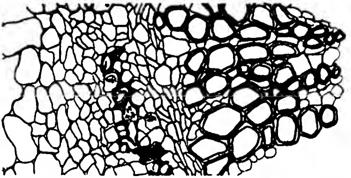

FIG. 1—Transverse section through cane of infected rose showing necrosis of phloem. Some cells have collapsed, others have thickened walls and gum is present.

Rose Wilt Infected Leaf

Young leaves in the reflexed condition showed no histological differences from healthy leaves. Examination of sections cut at thicknesses of 3–12μ and stained in a variety of ways failed to show the presence of intra-cellular inclusions. In the course of observations on the starch content of healthy and infected leaves, using the iodine staining technique, it was noticed, however, that in reflexed leaflets several minute colourless areas of pinprick size showed amid the general black stain due to the presence of starch. These small non-starch areas were not seen in healthy leaves. On close visual examination of fresh infected leaves, which were of comparable age to those iodine tested, no trace of any lesions could be detected. Examination of older leaves which had not dehisced showed that in some cases visible lesions were present. These were circular to irregular in shape, and of red-brown colour. Iodine staining showed an absence of starch around these spots. Sections cut through them revealed yellowing of palisade and of spongy mesophyll cells and the presence of gum-like deposits in affected cells (Plate XIV., figs. 2 and 3). Examination of cells in the vicinity of the necrosed regions showed the presence of a differential staining body generally situated close to the

nucleus (Plate XIV., figs. 6 and 7). These intra-cellular inclusions or X-bodies were oval or spherical in shape, and in some cases were comparable in size to the nucleus. The cells in which these were observed were mainly of the palisade layers fairly close to those showing necrosis or gum formation. They were present also in spongy mesophyll cells, but were not observed in epidermal cells. Owing to the presence of breakdown products in cells in a necrosed region, it was not possible to observe X-bodies in them. Nuclei in such cells were very much swollen as were also the chloroplasts.

Experiments on Transmission.

Mechanical Inoculation.

The disease is transmitted with difficulty, but it has been obtained in several cases by the following method. Infected leaves are ground in a little water to which fine emery powder is added and the extract pressed through cheesecloth. The virus containing juice is then rubbed over the surfaces of leaves of healthy plants, using the forefinger covered by a cheesecloth strip. Injection of virus juice using capillary tubes inserted into the canes near the bases and axils of petioles also produced infection. Using roses grown from cuttings, symptoms have been found to develop ten to twenty days after inoculation. Considerably greater difficulty was experienced in obtaining successful transmissions in rose plants growing in the open. In a group of 40 inoculations in the field only four proved successful. Controls remained healthy during the experiment.

Cross Inoculation Experiments.

Suitable members of the family Rosaceae were selected in attempts to transmit Rose Wilt by the mechanical inoculation method, but no clear-cut positive results were obtained. In the case of *Geum coccineum* and *Poterium sanguisorba* a suggestive recurving of the leaflets occurred in inoculated plants a few days after inoculation, but no further symptoms appeared.

To test a possibility that the symptoms of rose wilt might be really due to the virus of Tomato Spotted Wilt, a virus which produces diverse symptoms in a wide variety of horticultural plants, cross inoculations using expressed juice were made from infected roses to *Nicotiana tabacum* (White Burley Tobacco), *Nicotiana glutinosa*, and *Solanum lycopersicum* (Tomato variety Marglobe). No disease condition was produced by these inoculations. Conversely, it was not found possible to induce disease in roses by inoculation with Tomato Spotted Wilt virus. It is therefore concluded that these two diseases must be regarded as being caused by different viruses.

Transmission by Budding.

The procedure adopted was to take buds in mid-summer from canes of plants which were showing the dieback condition in a mild form in some shoots. Insertion of the buds into healthy plants was made towards the base of ripe shoots, using the T-bud method.

Considerable difficulty was experienced in getting the infected buds to take successfully owing, it is believed, to the progress of the disease in them. In the experiments so far concluded 40 healthy plants have been used. Of these twenty were budded, using buds from infected plants. The other twenty served as controls, being budded from healthy stock. In the test series union was successfully effected in only four plants, the infected buds in the other sixteen plants shrivelled and died. Of the four plants in which union was obtained two developed typical rose wilt symptoms Buds inserted on the control plants took well and these plants remained healthy. Although the number of successful transfers was small, the fact that they were well controlled gives dependability to the result. Further experiments using the patch-grafting method are being tried to obviate the difficulty of working with buds weakened by the virus.

Experiments on Insect Transmission.

The spread of the disease in gardens during one of its periodic visitations strongly suggests that an insect vector is involved. In a search for such a possible insect transmitter a number of experiments have been carried out. Different species of aphides from diseased rose plants have been tested for infectivity, but the results so far have been to a large degree negative, and will not be reported in detail. It should be pointed out that the search has been of an exploratory rather than of an exhaustive nature and is being continued as opportunity permits.

Serology.

The technique of serology was applied to the study of Rose Wilt Virus to determine whether it was antigenic, that is, capable of stimulating the production of precipitating and other antibodies when injected into rabbits, and also to determine whether this virus and Tomato Spotted Wilt were serologically distinct. The wide host range in horticultural plants and the diverse symptoms produced by Spotted Wilt virus made this a desirable test. Antisera for Rose Wilt and Tomato Spotted Wilt were prepared, using essentially the methods of Chester (1935).

No virus specific precipitin reaction was obtained, however, in either case. Mushin (1942) working in this laboratory has, in the course of more extensive serological work, obtained the same results for Rose Wilt. Chester (1937) concluded that Tomato Spotted Wilt was non-reactive serologically. He pointed out that viruses which so far have been shown to be serologically inactive

have in common the characters of being difficult to transmit by mechanical means and of being relatively unstable in vitro. Though little is known as yet of the properties of Rose Wilt virus, the relative difficulty of its transmission by mechanical means and its serological inactivity makes it probable that it belongs to the group of viruses which are unstable in vitro.

Since neither Rose Wilt nor Tomato Spotted Wilt produce active sera they cannot be shown to be separate viruses by this means. As pointed out in an earlier section, however, Tomato Spotted Wilt virus could not be transmitted to Rose plants, and on this evidence, together with the fact that no X-bodies have been observed in Spotted Wilt infected plants, it is concluded that the two viruses are distinct.

Observations on Susceptibility of Rose Varieties.

In Victorian gardens the great majority of roses grown belong to the Hybrid Tea Group. Pernetianas, Hybrid Perpetuals, and Tea roses are also grown, but not in any abundance Of these four groups observation has shown that the Pernetiana roses, or those roses with some of the Pernetiana strain in them, are most susceptible to Rose Wilt.

Golden Emblem and Ville de Paris are two outstanding examples of Pernet roses which take wilt badly. The popular Hybrid Tea roses, while as a class being somewhat more resistant than the Pernetianas, are nevertheless very subject to the disease. Some gradation in intensity of infection occurs. Rose Wilt Virus has been observed on the following Hybrid Tea roses in severe form:—Dame Edith Helen, Sunburst, Yvonne Vacherot, Mme. A. Chatenay, Columbia, Lorraine Lee, Mrs. McKee, and Etoile de Hollande On the other hand, the varieties Sunny South and Chateau de Clos Vougeot appear to be more resistant to the disease.

Tea roses appear to have relatively the greatest resistance to Rose Wilt and, in fact, no certain cases of wilt on tea roses has been brought to the notice of the author.

Comparison of Rose Wilt with Other Rose Viruses.

Three virus diseases of rose other than Rose Wilt have been described, one in Italy and two in the United States of America. Rose Mosaic (White, 1932; Thomas and Massey, 1939; Brierley and Smith, 1940) and Streak of Roses (Brierley and Smith, 1940) in the United States of America appear to be quite distinct from Rose Wilt.

Gigante's (1936) new virus disease of roses in Italy has, however, many features in common with Rose Wilt, while there are also apparently certain minor points of difference. A comparison in summary form of external and internal symptoms of the two diseases is presented in Table 1, as are also symptoms of Streak and Rose Mosaic. Symptoms which Rose Wilt and the

Italian Rose disease have in common are the very characteristic recurving and balling of young leaflets, followed by defoliation from the apex downwards. This again is followed in both diseases by the browning and blackening of defoliated canes. Primary symptoms, such as the presence on the leaves of dark spots, and yellowish-brown necrotic areas surrounded by a blackish halo, as described by Gigante, do not occur in the Australian Rose disease. The presence of leaf spotting may occur some considerable time after "balling" and when defoliation fails to occur. Gigante also stresses the early appearance on infected canes of reddish-brown raised areas. As indicated earlier, such raised spottings have sometimes been observed on canes of plants which have been infected with the Rose Wilt for more than one season, and in which a certain degree of recovery from the disease is apparent.

TABLE 1.—COMPARISON OF SYMPTOMS OF ROSE VIRUSES.

——	Rose Wilt Virus.	Gigante's New Italian Rose Disease.	Streak Disease.	Rose Mosaic.
External Symptoms	Recurving and balling together of leaflets on the petioles. Leaves become brittle and defoliation occurs commencing at the apex and working downwards. After defoliation rapid dying back of the canes occurs	Leaflets recurving and balling. Blistering of leaves and the development of small dark spots on the leaves. Reddish lesions on the canes. Defoliation working from apex to base. Flowers show deformation	Brownish rings and brown vein banding. Water soaked ring patterns in canes	Rose Mosaic 1. (Thomas and Massey) Small chlorotic spots somewhat angular or fringed in appearance. Distortion of leaf blade. Flowers deformed and pale in colour Rose Mosaic 2. Chlorotic lines, bands and broad blotches in the leaf blade with or without distortion Rose Mosaic 3. Broad chlorotic blotches in the leaf blade. Dwarfing of the plant
Internal symptoms	Necrosis of cortex, medullary ray cells and of the phloem Suberization of walls and gum formation Intracellular inclusions present in leaves	Necrotic cells present in stem parenchyma. Necrosis of cells in the leaf Intracellular inclusions present	None recorded	None recorded
Transmission	Mechanical inoculation and budding	Mechanical inoculation. Insect vector believed to be a species of *Macrosiphum*	Budding and grafting	Budding and grafting

In so far as the histology of the two diseases is concerned there is agreement with Gigante as to the necrosis of cells of the cortex and the medullary rays of infected canes. The formation of cork cells in the cortex cutting off the necrotic cells, which he records, has not, however, been seen in the case of Rose Wilt. Gigante makes no reference to necroses of the phloem in the Italian rose disease, and it is not possible from the photomicrographs in his paper to tell whether any is present.

Intra-cellular inclusions have been found in diseased leaves in both viruses. Gigante finds them, as does the author, in leaves which are showing some necrosis of cells. In the case of the Italian rose disease it appears that the leaf lesion symptom and X-bodies occur early, whereas in Rose Wilt, necrosis of cells has been found only in those leaves which remain attached for a long time, and X-bodies cannot be seen in the balled-up leaves which absciss early.

Both viruses are sap transmissible with difficulty, and there is evidence that Rose Wilt is transmitted by budding. The insect vector in the Italian rose disease is believed to be a species of *Macrosiphum*, but no conclusion has been reached regarding an insect vector in the case of Rose Wilt.

It would appear, despite minor symptom differences, that the viruses are the same. Confirmation of this must await further information on the properties of the viruses and the discovery of useful differential hosts.

CONTROL.

The view was earlier expressed (Grieve, 1933) that infection might be carried by secateurs during pruning operations on healthy and virus-infected plants. The relative difficulty of transmission by mechanical inoculation leads one now to consider that such a method of spread is unlikely in practice. Nevertheless, sterilization of secateurs in dilute formalin remains a useful general precaution.

The experiments on budding have shown that in practice this is a possible method of transmission of Rose Wilt. Badly infected plants as a source of buds are of course not in question. The danger lies in utilizing rose plants which have been only slightly affected or have made an apparent recovery.

Evidence as to the relative susceptibility of rose types to wilt is incomplete. Members of the Pernetiana, H.T. and H.P. groups have all been found subject to the disease Those varieties in which the Pernetiana strain has been incorporated do show a greater degree of susceptibility, and should be avoided.

The rapid and random spread of the disease in gardens during certain seasons suggests that an insect vector is concerned, although none as yet has been implicated. The only effective remedy against spread at the present time is the removal and burning of the infected plant as soon as the symptoms become manifest.

SUMMARY.

1. The external symptoms of Rose Wilt virus are briefly reviewed and an account is given of the morbid anatomy of infected plants. Necrosis of cells occurs in the cortex, medullary rays, and in the phloem of the canes, as the disease progresses

from the stage of reflexing of leaflets to their defoliation Micro chemical tests indicated that the necrosis was accompanied by suberization of walls and the secretion of a gum-like substance

2 Intra-cellular bodies were found associated with the nucleus in leaves which remained for some time on the plant In the majority of cases the leaves abscise shortly after becoming reflexed and before lesions develop At this stage no X bodies were seen

3 Results of experiments on transmission by mechanical methods and serological evidence suggest that Rose Wilt is an unstable virus In a small percentage of cases successful transmission by T budding was effected

4 Control measures are discussed in the light of the experimental results obtained The author is indebted to Prof Woodruff for help and for facilities for the serological tests

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Explanation of Plates

PLATE XIII

FIGS 1 and 2—Diseased plants with reflexed and balled up leaves

FIG 3—Artificially infected plant showing both reflexing and defoliation stages

FIG 4—Infected plant approaching the dieback stage of disease

PLATE XIV

FIG 1—Transverse section through leaf X—bodies in association with nuclei X = intracellular body n = nucleus

FIG 2—Section of leaf showing the origin and spread of the necroses

FIG 3—Section of leaf magnified to show secretic palisade cells on left.

FIG 4—X—body in association with the nucleus in a cell of the spongy parenchyma

FIG 5—Section of the cane showing advanced necrosis of the Phloem. Some of the cells are obliterated and others are filled with gum.

FIG 6—Palisade cells of leaf showing presence of X—body

FIGS. 7 and 8—High power magnifications from section in Fig 1 to show intracellular inclusions

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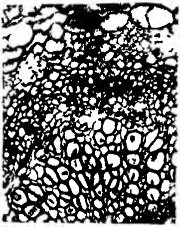

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[Proc Roy Soc Victoria 54 (N S) Pt II 1942]

Art XII —*Note on the Oil of Subterranean Clover Seed (Midseason Variety)*

By A MARGARET McARTHUR B Sc

[Read 11th December 1941 issued separately 31st August 1942]

Subterranean Clover forms large quantities of seed which is known to contain a good deal of oil The following examination of this oil was carried out at the suggestion of Mr H A Mullett Director of Agriculture for Victoria The seed was obtained through the Department of Agriculture

The oil was extracted with ether in a Soxhlet Extractor from the finely ground seed and after removal of the ether it was dried by heating in a boiling water bath CO_2 being passed through the flask to prevent oxidation The amount of oil obtained was found to be 16 8 per cent of the whole seed

Other samples of oil were obtained by pressure but it was found necessary to moisten the seed with water (about 5 per cent of the weight of the seed) for 24 hours before any quantity of oil could be obtained in this way The finely ground seed was then pressed in an experimental hydraulic press at a pressure of 1 000 1 500 lb per square inch (We are indebted to Mr H E West of the William Angliss Food Trades School for preparing the samples of pressed oil) The yield of oil by this method was 5-6 per cent

The chemical tests carried out were the Saponification Value Reichert Meissl and Polenske numbers and the Iodine Value The Saponification Value is a measure of the soluble volatile fatty acids i e the lower acids up to caproic (C_6) and the Polenske value is a measure of the insoluble volatile fatty acids present (acids from C_6 to about C_{10}) The standard methods were used for these determinations The Iodine Number which is an index of the unsaturated acids present was estimated by Wij s solution (iodine monochloride in glacial acetic)

	Pressed	*Extracted*
Saponification Value	201	211
Reichert Meissl No	1 6	1
Polenske No	0 7	0 8
Iodine Value	108	111
Refractive Index at 19 1° C	1 4680	1 4703
Unsaponifiable Matter	1 97%	—

The results are on the whole slightly higher for the extracted oil This is probably due to a trace of water in the pressed oil

A further estimation was made of the unsaturated fatty acids in the oil by the method of Hilditch which depends essentially

on the differing solubilities of the lead salts of the saturated and unsaturated acids in ether or alcohol The mixed fatty acids were first prepared About 20 gm of oil was saponified with alcoholic potash and most of the alcohol then removed The soaps were dissolved in water and the unsaponifiable matter was then extracted with ether The soaps were next converted into free fatty acids by warming with dilute H_2SO_4 (an atmosphere of nitrogen being used to prevent oxidation) and these acids were then extracted with ether and dried under low pressure at 80–90°C

To a boiling alcoholic solution of the mixed fatty acids lead acetate in boiling alcohol was added The solution was then cooled slowly to 15 degrees and left to stand overnight The insoluble lead compounds were filtered off the alcohol removed by distillation and the unsaturated acids remaining were dissolved in ether This solution was washed twice with dilute acetic acid to set free the acids and the ethereal solution of these washed with water until the aqueous layer was no longer acid Any fatty acids retained in the water used in this process were recovered by extracting with a further quantity of ether which was then added to the original ethereal extracts The last traces of ether and water were removed by heating in a water bath under reduced pressure The percentage of unsaturated acids was found to be 61 5 per cent

Summary

The oil obtained from clover seed contains about 60 per cent of unsaturated acids and as the Reichert Meissl and Polenske values indicate very few acids either saturated or unsaturated below C_{10} Its Iodine Value is considerably below that of Linseed and the other oils used for paint manufacture but since drying properties of oils are not wholly dependent on the Iodine Value, this point may be worth further investigation

The following table shows that this oil is similar in character to Olive Maize and Cotton Seed Oil

	Saponification Value	*Iodine Value*	*Unsaturated Acids*
Olive Oil	190 5	85	85%
Maize Oil	189 93	115 25	90%
Cotton Seed Oil	191 5	108 16	75%
Clover Seed Oil	201 11	108 11	61%

Tests for the presence of vitamin A were done on the unsaponifiable matter of the oil by the Carr Price Test (antimony trichloride in chloroform) These tests were entirely negative

This work has been carried out in the Department of Biochemistry of the University of Melbourne and thanks are due to Professor W J Young for suggesting the line of investigation and for his help and advice throughout

[PROC. ROY. SOC. VICTORIA, 54 (N.S.), PT II, 1942.]

ART. XIII.—*The Bearing of the Tertiary Sub-Basaltic Deposits on the Palaeogeography of the Lilydale District.*

By EDMUND D. GILL, B.A., B.D.

[Read 11th December, 1941; issued separately, 31st August, 1942.]

Contents.

Introduction.

Selwyn (1856) and Murray (1887) made early references to the Older Basalt and accompanying deposits at Lilydale, the latter believing them to be connected with an ancient river flowing from Hoddle's Creek through Lilydale and Kangaroo Ground to Melbourne. Cresswell (1893), Stirling (1899), Morris (1914), and Keble (1918) have also commented on these deposits and references to their views have been made under appropriate sections.

Extent and Character of the Deposits.

The deposits now to be described are to be found in the parishes of Mooroolbark, Lilydale, and Gruyere. The Older Basalt of this area consists of highly decomposed residuals capping the hills. The largest residual is that at Lilydale, which is 2½ miles long and from ¾ mile to 1½ miles wide. The sub-Older-Basalt deposits are fluviatile in origin and consist of clays, sands, quartzites, conglomerates, gravels, and ferruginous grits. The sands and quartzites are known to be fossiliferous.

Clays.

At Melbourne Hill, Lilydale (locality 2 on map, Gill 1940, p 252), a bed of clay outcrops in the road cutting under the basalt and unconformably over the bedrock of Yeringian strata. Similar clay is seen on Edward Road where the northern boundary of the basalt residual crosses that thoroughfare, and at Cave Hill. Cresswell (1893) shows (fig. 10) "Whitish clay" between the limestone and the basalt in the railway cutting just south of Cave Hill. Stirling (1899) refers to it as "basaltic clay."

Sands.

Current bedded sands can be seen outcropping in the paddock at Black Springs on the north-eastern corner of the junction of the Lilydale Highway and Edward Road where they rest unconformably on fossiliferous Yeringian sandstones and mudstones. This is the locality from which Mr. W. H. Ferguson collected fossil leaves, to which he has referred as "Laurel leaves" (Ferguson, 1931, p. 52). Dr. R. T. Patton has kindly examined these leaves, and determined them as *Nothofagus* sp. Sub-basaltic river sands also occur at Melbourne Hill, Lilydale, and in the railway cutting immediately south of Cave Hill (22 miles 9½ chains to 22 miles 12 chains). The largest of the extant deposits is at Cave Hill where they have been revealed by quarrying operations. Specimens have been collected which show the gradation from sand into the accompanying quartzite, which was formerly thought to be of Palaeozoic age. Silicified wood (M U G D. Fossil Coll, reg. no. 1737) from the Cave Hill sands has been sectioned at the Geology Department of the University by Mr G. Baker, and determined by Miss A. M. Eckersley as referable to the family Lauraceae, probably the genus *Beilschmiedia*

An interesting feature of the Cave Hill sands is their inclusion of sheared and crushed pebbles. Such have not been found in any of the other sub-basaltic deposits of the district. As they are embedded in sands, their crushing can only have occurred *in situ* if they were formerly cemented and have since been decemented. They may have been derived from a crush zone elsewhere but the displaced edges do not show wear due to transport by water. The pebbles are of whitish, very hard quartzite.

Sands occurring in the parish of Gruyere will be described in a subsequent section.

Quartzites.

These occur mainly in the parish of Mooroolbark, and consist chiefly of ridges of meridional trend running from Cave Hill towards Mooroolbark itself. On the eastern side of Cave Hill the quartzite appears to extend over the toscanite which is the lowest member of the Dandenong Mountains igneous suite. This extension is not unlikely since there is an outlier of toscanite north of Cave Hill and half a mile north-west of Lilydale railway station. The Olinda Creek alluvium in this area probably rests on a bedrock of toscanite. East of Cave Hill the toscanite actually outcrops in the bed of Olinda Creek.

Cresswell (1893) drew a geological section through Cave Hill, and stated that the quartzites and conglomerates are Upper Silurian (= present Silurian) in age, and are conformable with the limestones of Cave Hill. Morris (1914) referred the sands to the Tertiary period, but considered the quartzites and conglomerates to be Palaeozoic in age. The possession by the

quartzite ridges of a strike similar to that of the Palaeozoic bed-rock has lent colour to this interpretation. Their elevation above that of the surrounding Palaeozoic strata was explained as being due to the more resistant character of the quartzitic beds. Some 10 years ago Mr. W. H. Ferguson mapped the area (Geol. Surv. Vic. unpublished map) and indicated the age of the quartzites and associated deposits as "Lower Tertiary." The excavation of the limestone at Cave Hill quarry in recent years has clearly exposed the unconformity between the limestone and the over-lying sands-quartzite association. A horizontal bore at right angles to the strike in the eastern wall of the quarry has proved the extension of the limestone for 276 feet. Moreover, the discovery of the fossil wood in sands under the quartzite proves the Tertiary age. Furthermore, on the north side of Cave Hill there have been collected numerous pieces of quartzite containing holes which are possibly the casts of sticks and twigs. Quartzite also occurs with the sands in the railway cutting south of Cave Hill (22 mls. 11 chains). It also occurs in the parish of Gruyere as will be mentioned subsequently.

Conglomerates.

To the south of Cave Hill there are conglomeratic beds which have been silicified to varying degrees. Large pebbles occur in a matrix consisting of cemented quartz sand and gravel, and they consist chiefly of quartz and quartzose sandstone. In the parish of Gruyere small local occurrences of pebbly gravels grading into conglomerates are found.

Gravels.

Deposits of uncompacted water-worn fragments which are larger in size than those of the sands may be described as gravels On the northern boundary of section 21, parish of Yering (Military map grid reference 340,470 Ringwood Sheet) there is a small residual of Older Basalt, and on its southern side quartz pebbles are common in the cultivated ground, indicative of a deposit of sub-basaltic gravel. There is a deposit of gravel north-east from this point, across Edward Road, also on top of a high hill, and this is regarded as being the eastern extension of the same sub-basaltic accumulation. The gravel is 15 to 20 feet thick and contains pebbles up to 10 inches in diameter.

At the upstream end of Yering Gorge there is a deposit of gravel some four to five feet thick, about 30 feet above the present River Yarra level. The deposit is aligned parallel to the river course and was evidently deposited by that stream. Ferguson mapped this and a less conspicuous patch at about the same height at the other end of the Gorge with the other "Lower Tertiary" rocks. These gravels are between 100 and 150 feet lower than the undoubted sub-basaltic deposits. However, no similar deposits of gravel by the Yarra are to be seen anywhere in the

vicinity, so possibly these two gravel patches are sub-Older-Basalt gravels which were re-distributed by the Yarra when it was at a much higher level than it is now.

Thick deposits of gravel also exist in the parish of Gruyere, further east (see map, fig. 1). On the road often called Gruyere Road which proceeds northwards between sections 6 and 7 of that parish from Victoria Road, there is a small branch road to the east one mile north of Victoria Road. At this corner sub-basaltic river sands can be seen resting unconformably on grey Palaeozoic shales in a small road cutting. The sands show signs of current bedding, and over them is a considerable thickness of gravel as is shown by the spoil heaps from nearby shallow shafts which were sunk in search for gold. Pebbles of all sizes up to a foot in diameter are present in these gravels. As one continues to the higher ground further south the deposits are seen to be still present. The outcropping of these deposits all the way up the slopes indicates that the sub-basaltic sands and gravels here are 30 feet or more in thickness.

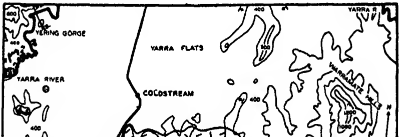

FIG. 1.—Map showing Older Basalt and Associated Deposits of the Lilydale District.

In other places in the parish, too, the thickness and extent of these sub-basaltic accumulations is demonstrated. North and south of the Warburton railway line east of Wandin pebbles are common in the cultivated ground. South of the line, on a small stretch of road parallel to it, two shafts have been sunk through the gravels. The debris is full of well-rounded pebbles of quartz and siliceous sandstones up to 7 inches in diameter. In the railway cutting nearby can be seen a decomposed intrusive rock in indurated Palaeozoic sediments. Half a mile away, on the other side of Victoria Road almost opposite the end of Burgi's

Hill road, a small outcrop of granodiorite porphyrite (G. Baker determination: M.U.G.D. Slide Coll. No. 5185) about 15 feet in diameter and about a foot high was blasted from a small ridge running east and west. The rock was outcropping through the Older Basalt and was removed to facilitate cultivation. This rock, which is rich in quartz, may be one of the sources for the quartzose materials of the sub-basaltic deposits.

Palaeogeography.

The extent and thickness of the sub-Older-Basaltic deposits of the Lilydale District appear to the writer to be incongruous with the view that they belonged to a stream originating a few miles away on the Kinglake Plateau. The quartzite ridges rise 50 feet and sometimes more above the bedrock At Cave Hill up to 30 feet of sands can be seen in the quarry face surmounted by some 10 feet of quartzite. Also the deposits are laterally widespread, extending 1½ miles even in extant formations. Furthermore, the material must have been transported for some distance because there are no sources nearby from which there could possibly originate so great an amount of quartzose materials. What remains now must be only a fraction of the original deposits. It is thus clear that a river of some magnitude must have flowed over this area, but its course as explained by Keble (1918, p. 158) is inadequate to explain the occurrences. Keble considered that a river, commencing on the Kinglake Plateau, flowed alongside the Wurunjerri Range, followed a course parallel to the present Steel's Creek, then proceeded southwards through Lilydale to the sea, probably near Frankston. He regarded the high ground east of Steel's Creek as an uncovered residual which represented the course of the pre-basaltic stream. This area, however, consists of very steep country which constitutes the erosional escarpment of the Kinglake Plateau. A prominent hill called "The Pinacles," 912 feet high, is situated there, and in two miles southwards the elevation drops to 300 feet. The Steel's Creek area cannot be considered as part of the course of the pre-basaltic stream.

The relative levels of the sub-basaltic deposits show that the pre-basaltic river flowed southwards through Lilydale, so if the upstream part of this ancient river did not come from the north (Kinglake Plateau), it must have come from the west or the east. It did not come from the west because along that flank ran the Wurunjerri Range (Keble, 1918; Hills, 1934). It must therefore have come from the east. However, to the immediate east is the Dandenong Range, terminating to the north in a long tongue of toscanite which extends as far as Coldstream. The River Yarra has reduced the country to the north of the toscanite below the level of the pre-basaltic terrain, so no trace of the ancient river can be found there, but immediately to the east

of the toscanite flow, in the parish of Gruyere, big deposits of sub-basaltic materials are found. The character and extent of these are comparable with those of Lilydale, and show that this is the main course of the pre-basaltic river. Probably the reason which caused physiographers to look to the north for the continuation of the sub-basaltic river is that it was believed that the Woori Yallock basin was drained by a river which flowed southwards through the Gembrook Gap (Gregory, 1903; Keble, 1918). Edwards (1940) has recently shown that the pre-basaltic terrain in this area had a northerly and not a southerly slope. The evidence brought forward by Edwards (and now extended) of a basin with a northerly slope is so clear and definite that an indecisive ecological argument as developed by Clark (1941) based on the distribution of *Euastacus* cannot discount it.

Mr G Baker, M.Sc, kindly made a heavy mineral analysis of a sample of sub-basaltic gravel collected from the location of the mine shafts south of the Warburton railway line near Burgi's Hill Mr. Baker's report, which throws light on the origin of the sub-basaltic materials, is as follows:

"Macro: Grain size ranges from very fine clay to pebbles of quartz up to 10 mm. diameter and sandstone up to 32 mm. Quartz translucent, and mainly granitic A few grains of reef quartz present. Grains principally angular Bleached biotite present in fairly large flakes. Occasional small pebbles of limonite were observed; also a few felspar grains and some of kaolin.

Micro: Heavy minerals obtained by sieving and using material 0·5 mm. and under, washed free of fine clay, then separated in bromoform (S.G 2·88) The proportion of heavy minerals to others is small. The minerals present are—

Ilmenite—abundant in heavy mineral residuum.
Biotite—brown and bleached.
Tourmaline—rare angular fragments and prisms, one rounded (waterworn).
Zircon—rare Yellow and colourless crystals; some acicular, some showing 'torpedo' habit, one zoned, few water-clear, some showing normal prism and pyramid faces; a few contain inclusions. One waterworn.
Rutile—rare prisms
Cassiterite—rare grains
Anatase—one crystal (blue variety).
Brookite—one crystal.
Staurolite—one or two grains.
Topaz—rare grains.
Limonite and Leucoxene—occasional pseudomorphs after ilmenite.

Note.—The presence of fresh biotite, the angularity of most grains, the occurrence of well-preserved crystal forms in zircon, rutile, and some of the tourmaline, and the abundance of ilmenite, indicate derivation from a nearby acidic igneous mass and contact zone."

This report deals with material which lies to a thickness of 30 feet or more over the intrusion reported earlier in this paper. The origin of the material must be sought upstream from this point. If the pre-basaltic stream flowed southwards, then it is impossible to find an adequate source for the great quantity of

sub-basaltic materials On the other hand if the stream flowed northwards in this area an adequate source for the material can be found in the granitoid rocks and dacites bordering on the Woori Yallock basin A further piece of corroborative evidence is seen in the fact that the Older Basalt of the residuals at Silvan (in the Woori Yallock basin) and at Lilydale are both of the Flinders type (Edwards 1939) whereas that at Berwick (south of the Gembrook gap) is different

That the pre basaltic river flowed in a mature valley is shown by the wide lateral extent of the fluviatile deposits and secondly by the gradient of the stream as shown by the elevations of the bases of the lava residuals At Lilydale the fluviatile deposits extend for the full width of the lava residual viz 1½ miles and may originally have been wider At the south border of the parish of Gruyere the base of the older basalt is between 550 and 600 feet above sea level while west of Coldstream (Edward Rd) it is approximately 450 feet and at Lilydale it is about 400 feet These figures indicate a gradient in the region of 15 feet fall per mile which is approximately the devexity of the Dandenong Creek

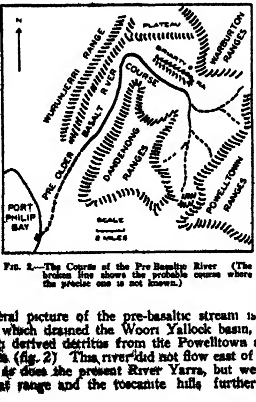

FIG. 2.—The Course of the Pre Basaltic River (The broken line shows the probable course where the precise one is not known.)

The general picture of the pre-basaltic stream is thus of a large river which drained the Woori Yallock basin, with tributaries which derived detritus from the Powelltown and Dandenong Ranges (fig. 2) This river did not flow east of the Warramate Hills as does the present River Yarra, but west of them, between that range and the toscanite hills further west. In

Oligocene times, which is probably the age of the basalt, the Warramate Hills were very likely continuous with the prominent V-shaped ridge to the north-west of them, for even now there are quite prominent hills in between them which have no Older-Basaltic deposits on them. The V-shaped ridge is caused by the southerly pitch of a highly siliceous Yeringian horizon folded in a syncline, as surmized by Morris (1914). Its continuation to the south is seen in the prominent ridge which runs parallel with Boundary Road. The pre-basaltic river flowed to the north-west between the eminences just mentioned and the toscanite mass (fig. 1). The river quite probably continued in that direction until it met the Wurunjerri Range between Yarra Glen and Yering Gorge, whereupon it was deflected southwards between that Range and the Dandenong mountains, thus passing through Lilydale. The levels of the Older Basalt and associated deposits in the parish of Gruyere show that the Warramate Hills are not an "uncovered residual" (Keble, 1918), but a ridge of Palaeozoic sediments owing their prominence to their greatest hardness, i.e., to differential erosion (Hills, 1934; Edwards, 1940).

Relation to Alleged Faulting.

Another inference from the palaeogeography is that there has been no major faulting in the vicinity of Lilydale in Tertiary times. This has a bearing on the Senkungsfeld Theory of Jutson (1911), and the problem of the Yering Gorge. Jutson considered a fault to be present along Brushy Creek because of the presence of a well-defined scarp to the west and a lowland to the east which he termed the "Croydon Senkungsfeld." Hills (1934) explained this by differential erosion because of the presence of hard quartzitic sandstones on the scarp, and because the supposed fault closely followed the strike of the beds. This contention is supported by the study of the pre-basaltic terrain, and also by a survey of the lithological types present in the area. The alleged differential throw of the fault corresponds to the hardness of the rocks at the points given. Jutson wrote, "The difference in height at the various points (e.g., at the mouth of Brushy Creek, about 200 feet, at Croydon about 140 feet, and at the "Kopje" about 85 feet), between the Yarra Plateau and the Croydon Senkungsfeld, indicates approximately the throw of the Brushy Creek fault." At the mouth of Brushy Creek is a very hard dyke of quartz porphyry, at Croydon there are resistant quartzitic sandstones, and at the "Kopje" micaceous sandstones of a less resistant character. At the northern end of the "Senkungsfeld" Jutson made the Brushy Creek fault swing away to the east of north and pass along the margin of Yering Gorge, where he claimed that the Yarra is antecedent to the fault. Jutson's section of Yering Gorge (1911, Plate LXXXVI.) shows both sides of

the Gorge of equal height, but the section as drawn from the contours of the Military Map (which was not available to Jutson) appears as in fig. 3.

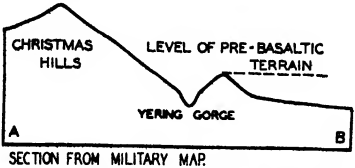

FIG 3.—Section on Line A—B in Fig. 1 across Yering Gorge. Horizontal Scale 2 in. = 1 mile, Vertical Scale 1 in. = 1/10th mile

The hill on the east side of the river is approximately the same height as most of the hills between Yering Gorge and Lilydale. The prominent ridge running from the basalt residual at Lilydale to the gorge is an "uncovered residual." At its northern end it has a small residual of basalt and deposits of gravel. It has no relation to the strike or hardness of the country rock and owes its elevation to its protection, until recently, by a capping of basalt. These hilltops, therefore, represent the level of the pre-basaltic terrain, whereas the high country to the west of the Gorge (the Christmas Hills) is really a spur of the Kinglake Plateau. The author is of the opinion that the Yering Gorge is due to the formation of a marginal stream where the Older Basalt was contiguous with the Wurunjerri Range. The stream was able to incise the bedrock more easily than the basalt, and so it cut down into the rocks which are hard compared with other Palaeozoic strata now exposed. The Yarra at this point is therefore a "superimposed" stream. When once the less resistant adjoining strata were uncovered by the removal of the basalt, they were more quickly reduced by the sub-aerial forces, and so there is a low saddle (262 feet above sea level) to the east of the Gorge. This is approached on both sides by embayments in the river valley, and in a short time (geologically) the remaining wall of rock, which is only about 25 feet above river level, will be reduced, and the river will short-cut across this point, leaving a wind-gap where the Gorge now is.

The views set out in this paper also suggest an origin for the Yarra flats different from that given by Hills (1934, 1935), viz., that the eruption of a volcano at Lilydale blocked the pre-basaltic river and caused it to overflow across a saddle in the Wurunjerri Range. Chapman (1909) was apparently the first

to suggest that the depressions on the hill west of Lilydale are volcanic vents. Morris (1914) supported the idea, but did so with reserve (p. 361). Hills adopted the idea to explain the deflection of the Yarra, but does not now himself adhere to that view (personal communication). Even if "Crater Hill" (as some residents call it) were a point of eruption, we cannot expect that well-shaped craters would persist since ? Oligocene times. The rock in this area is thoroughly decomposed, but occasional small pebbles of basalt are found in the red soil. Basalt is quarried for road purposes a little lower down the hill. There is no evidence of the presence of any fragmental volcanic rocks. The Yarra flats probably owe their origin to the formation of a local base-level by the Yarra because of its restriction at Yering Gorge between the quartzitic sandstones and the basalt. It is imagined that after the basalt flow had filled the valley of the pre-basaltic river, that a stream developed marginal to the flow, following the edge of the Kinglake Plateau in the north and continuing southwards along the edge of the Wurunjerri Range. The rocks on the edge of the erosion escarpment of the plateau in the vicinity of where Yarra Glen and Tarrawarra now stand would be more readily eroded than the resistant quartzitic rocks of the Wurunjerri Range. Thus the river upstream from the Gorge would tend to oscillate from side to side, widening its valley and in time becoming an aggrading stream (Hills, 1934, p. 169). There may have been other factors operating, but the formation of the flats has probably been due chiefly to the above cause. A similar local base-level, but on a smaller scale, has been formed between Yering Gorge and the Warrandyte Gorge.

Summary and Conclusions.

Fluviatile deposits of clays, sands, quartzites, gravels, conglomerates, and grits have been described from the parishes of Mooroolbark, Lilydale, and Gruyere. Fossil leaves and wood are named.

The aggregations indicate by their lateral extent, their depth, and their elevations above sea-level that a large river flowed there in a mature valley.

This river drained the Woori Yallock basin northwards, then flanking the toscanite mass at Coldstream, turned southwards through Lilydale. The river did not originate on the Kinglake Plateau as formerly thought.

The reconstruction of the pre-basaltic terrain shows that there has been no major faulting in the vicinity of Lilydale. This means, among other things, that some other explanation than that previously given is required to explain the Yering Gorge. A theory of its origin is advanced. The origin of the Yarra flats is also discussed.

Acknowledgments.

Facilities for study have been made available at the University Geology Department and for this I am obliged to Professor H S Summers It has been my advantage to discuss the significance of lava residuals with Mr R A Keble the author of a well known paper on that subject (Keble 1918) I am indebted to Mr G Baker M Sc for making a heavy mineral analysis of a sample of gravel and for cutting the sections of fossil wood The Director of the Geological Survey Mr W Baragwanath favoured me with a copy of Mr Ferguson s unpublished map I am indebted also to Dr F A Singleton for reading over the manuscript

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